The Electrical Trade

Know-How

MELTEC / MINTEC 208

WORLD OF ELECTRICITY & ELECTRONICS

CONTENTS

SIEMENS STEP 2000 - Basics of Electricity 1 &2

Workbook

LABs

Adrian De Angelis

MODESTO JUNIOR COLLEGE

A foreword

The Siemens STEP 2000 handbook has been downloaded from E and M (Northern California Siemens official distributor) website **www.enm.com/products/siemens.asp,** and printed with permission of E and M.

The reasons for choosing this handbook were its clarity, pertinence to the practical side of electricity and electronics, correspondence with the depth of this 208 course, low cost, and easy accessibility.

The pages of the Siemens' manual have been rearranged in order to align its content to this 208 course, but the material offered is, as a whole, exactly the same than the on-line handbook. All the reviews from the handbook were segregated from the text and complemented with quizzes and problems to make up the homework section of the course.

Siemens STEP 2000 final exam and its evaluation form are included. This form has to be faxed or mailed for evaluation to the indicated fax number or address (see form and details at the appendixes.) The whole Siemens STEP 2000 course can be completed on-line, final evaluation and certificate of completion included, at **automation.usa.siemens.com/step/default.html**

The Siemens' final exam presented in the STEP 2000 handbook **IS NOT** the exam required to approve this course, although the completion and approval of that exam will generate a certificate as is announced in E and M website. **The conditions to pass this 208 course are exposed in the syllabus.**

Since this handbook is free and available on-line, the cost of each copy is the cost of producing it. Complementary quizzes, problems, and labs are also charged only for their production cost, although these materials are from my authorship.

Adrian DeAngelis
Electronics Technology Instructor
Technical Education Department
435 College Avenue - ELTRN 112B
Modesto, CA 95350
deangelisa@mjc.edu

INDEX

Week 1	Introduction The Atom Basic Electrical Variables Scientific Notation Basic operation of Digital Multimeters (DMM)	Page 1
Week 2	Ohm's Law and Electric Power in DC Circuits	Page 31
Week 3	Series Circuits – Kirchoff's Voltage Law	Page 55
Week 4	Parallel Circuits – Kirchoff's Current Law	Page 77
Week 5	Series – Parallel Circuits	Page 101
Week 6	Capacitors & Coils	Page 133
Week 7	Midterm Review and Midterm Exam	Page 171
Week 8	AC Variables and the basic use of Oscilloscopes	Page 177
Week 9 & 10	Reactances Impedance Power in AC Power Factor	Page 205
Week 11	Electrical Machines	Page 239
Week 12	Introduction to Semiconductors I - Diodes	Page 265
Week 13	Introduction to Semiconductors II - Transistors	Page 291
Week 14	Introduction to Semiconductors III - ICs	Page 307
Week 15	Course Review – Study Guide	Page 315
Week 16	**Final Exam**	
Appendixes	DOE Excerpts of Mathematics – Scientific Notation Fluke DMM articles	Page 323

Siemens STEP 2000

Basic of Electricity 1 & 2

Includes Test Answer Form

Send this Test Answer Form to EandM for grading.
If you achieve a score of 70% or better and live in Northern California, we'll send you a certificate of completion! If you have any questions, contact EandM Training at 866.693.2636 or fax 707.473.3190 or training@eandm.com.

Attn: Step 2000 Training Department
EandM
55 Francisco Street Suite 330
San Francisco, CA 94133 707.473.3190 fax

WEEK 1

Notes

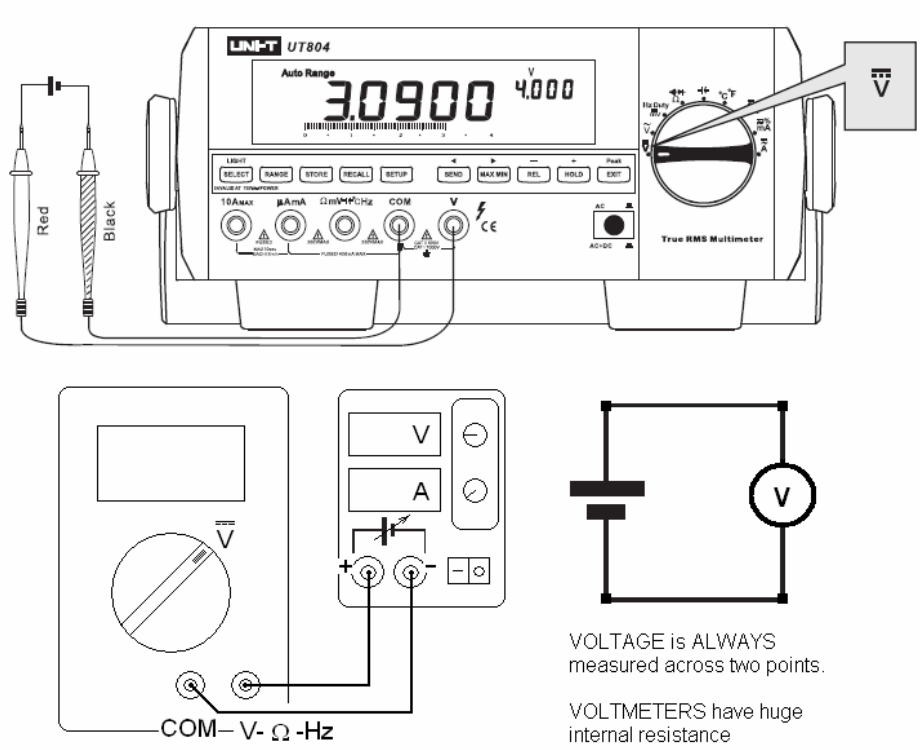
Notes

Notes

Notes

LAB #1 - DMMs

Measuring Voltage



Before performing voltage measurements, verify the integrity of the instrument's leads and case. This is a very important **precaution**, especially when working with **deadly voltage levels**. Refer to FLUKE's educational material ***"10 dumb things smart people do when testing electricity"*** in appendixes at the end of this manual.

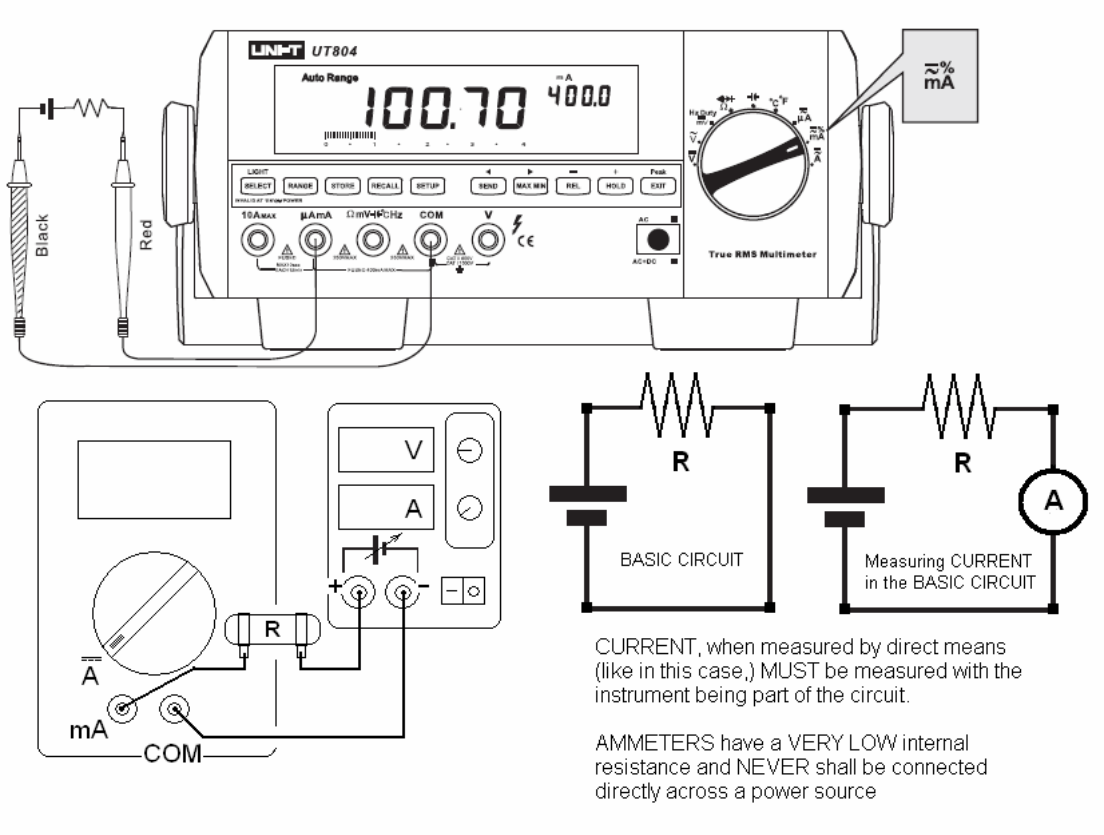
Lab Procedure:

1 Select DC Voltage scale – Higher range.
2 Connect Power Source (+) to DMM V-Ω-Hz (RED) and the (-) to COM (BLACK) port.
3 Turn Power Source ON and turn the voltage control until the voltage display on the power supply indicates 1.5V or close.
4 Record the DMM's reading.
5 Switch to the next lower RANGE and record the DMM's new reading.
6 Repeat for all the other DC Voltage RANGES.
7 When finish, turn the power supply OFF.

Range	1000	200	20	2	200m
Reading					

Notice that when there is a reading (no overload condition) the resolution depends on the scale selected. The resolution in the 1000V scale is 1 volt, in the 200V scale is 1 tenth of a volt (100mV,) in the 20V scale is 1 hundredth of a volt (10mV,) in the 2V scale is 1 thousandth of a volt (1mV,) and in the 200mV scale is a tenth of a thousandth (0.1mV = 100μV.)
The best resolution is obtained in the lowest possible scale (for the next lower scale the meter gets overloaded).
When measuring voltage using meters without auto-range feature, starting at the highest scale is a standard safety procedure (same criterion applies to the measurement of current).
Failing to do so may damage the instrument permanently and expose the operator to a flash incident.
Please refer to FLUKE's ***"ABCs of electrical measurement safety"*** at the Appendixes of this book

Measuring Current



When performing current measurement introducing the meter as part of the circuit, NEVER CONNECT AN AMMETER IN PARALLEL. Doing so:

a. It'll blow the internal fuse.
b. It might burn the instrument.
c. It might cause a severe short in the circuit under study, possibly damaging it, and possibly exposing the operator to an electrical flash.

Lab Procedure:

1 Set the power supply at 9V and 150mA max current – review Power Supply Setting Procedure explained in the handout delivered with syllabus
2 Turn the power supply OFF
3 Keep the DMM off and select in the DC Amps scale the highest range **for the fused port** (200m) – **BECAREFUL!** There is a 10 A port, but it is **UNFUSED**

4 Connect the Power Source's (-) terminal (BLACK) to the COM port of the DMM
5 Connect the Power Source's (+) terminal (RED) to one side of the provided industrial type resistor
6 Connect the other side of the resistor to the DMM mA port.

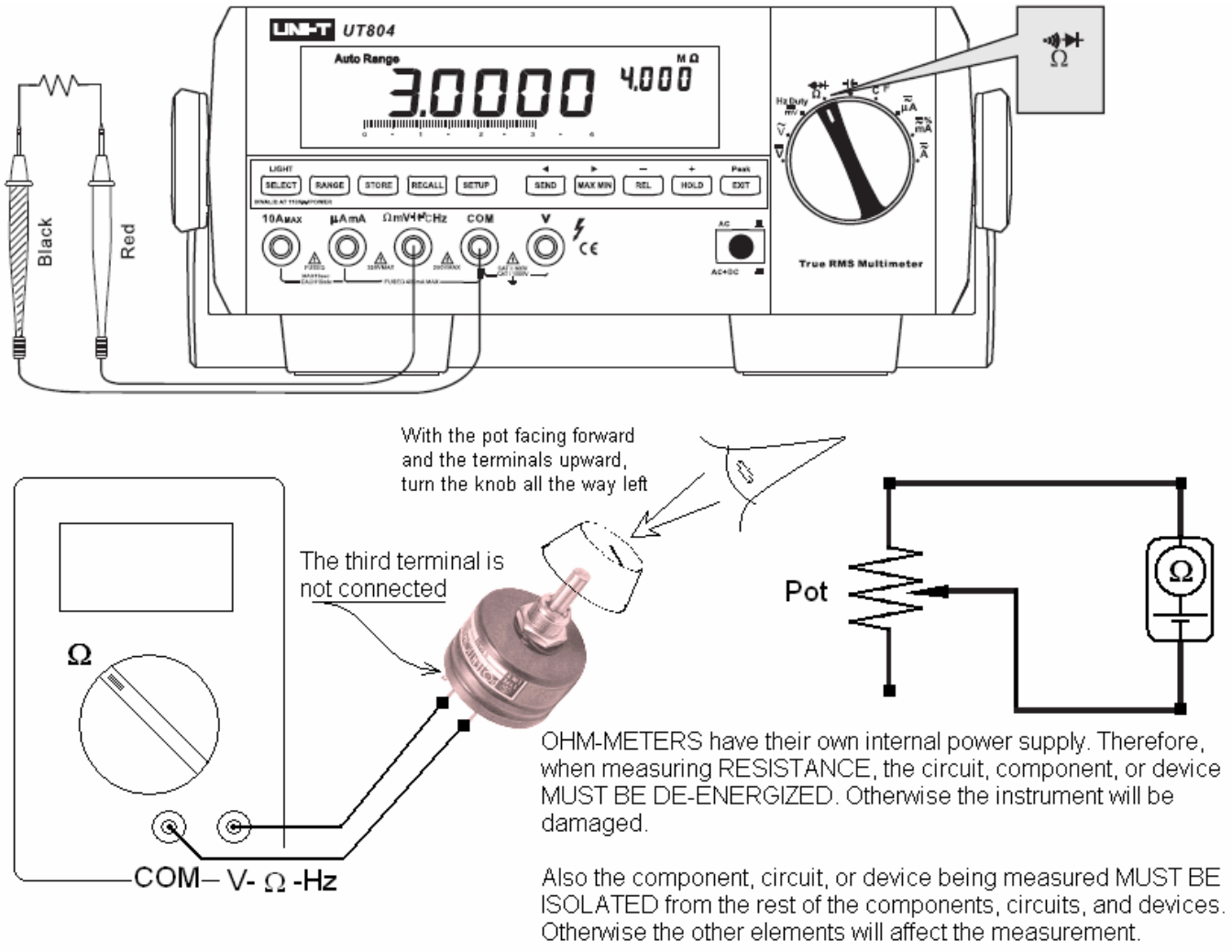
7 Turn the DMM ON – It will measure 0 mA
8 Turn the power supply ON – It will measure something in the neighborhood of 3 mA – If the reading reaches the pre-set level of maximum current it is an indication that the meter is been connected in the wrong way.
9 Record the reading for every DC Amperage range in the chart bellow.
10 Go back to DC Amps higher scale
11 Turn Power Source voltage control knob to 18V
12 Repeat step 9
13 Once it is all done, turn OFF the power supply

Range	200m	20m
1st set of readings at 9V		
2nd set of readings at 18V		

Notice that within the max limit established by the fuse, when the measured current exceeds the selected range, the ammeter displays an overload reading. Above the fuse rating, an overload current will blow the fuse. If the fuse is selected incorrectly, any of the events described before item 1 will occur.

In regard of the resolution of the instrument, the same considerations described in the former voltage experiment apply.

Measuring Resistance


UNI-T UT804
Auto Range
3.0000
4.000
MΩ
Black
Red
True RMS Multimeter
With the pot facing forward
and the terminals upward,
turn the knob all the way left
The third terminal is
not connected
Pot
Ω
COM– V- Ω -Hz
OHM-METERS have their own internal power supply. Therefore, when measuring RESISTANCE, the circuit, component, or device MUST BE DE-ENERGIZED. Otherwise the instrument will be damaged.
Also the component, circuit, or device being measured MUST BE ISOLATED from the rest of the components, circuits, and devices. Otherwise the other elements will affect the measurement.

NEVER use an ohm-meter in energized circuits, it can burn the instrument. Ohm-meters have their own internal power source.

Do not use an ohm-meter in a connected component either; it will give you a misleading reading.

1 Connect the middle and one of the end terminals of the provided potentiometer to the DMM ports (COM and V-Ω-Hz)
2 With the potentiometer facing forward and the terminals up, turn the potentiometer knob all the way to the left.
3 Set the DMM in Ω in the higher scale – 20M – and record the reading in the chart below.
4 Switch through all the resistance's scales and record the readings in the chart bellow until the 200 ohms scale is reached.

5 Switch the DMM back to the 20M scale and turn the potentiometer's knob at 9 o'clock
6 Repeat step 5. Afterward, turn the knob to 12:00, 3:00, and all the way to the right, repeating step 5.

Range	20M	2M	200K	20K	2K	200
1st Reading						
2nd Reading						
3rd Reading						
4th Reading						

The last scale marked with the symbol of a DIODE (⊣) and a sound wave (o))) it is called "CONTINUITY" and it is used to measure the internal electric field of diodes and very low resistances – generally anything up to 50 ohms is considered very low resistance. If the component, circuit, or device being measured has very low resistance, the instrument will beep. This is a handy feature when checking or troubleshooting circuits.

Introduction

Welcome to the first course in the STEP 2000 series, **S**iemens **T**echnical **E**ducation **P**rogram designed to prepare our distributors for the year 2000 and beyond. This course covers **Basics of Electricity** and is designed to prepare you for subsequent courses on Siemens Energy & Automation products.

Upon completion of **Basics of Electricity** you will be able to:

- Explain the difference between conductors and insulators
- Use Ohm's Law to calculate current, voltage, and resistance
- Calculate equivalent resistance for series, parallel, or series-parallel circuits
- Calculate voltage drop across a resistor
- Calculate power given other basic values
- Identify factors that determine the strength and polarity of a current-carrying coil's magnetic field
- Determine peak, instantaneous, and effective values of an AC sine wave
- Identify factors that effect inductive reactance and capacitive reactance in an AC circuit
- Calculate total impedance of an AC circuit
- Explain the difference between real power and apparent power in an AC circuit

- Calculate primary and secondary voltages of single-phase and three-phase transformers
- Calculate kVA of a transformer

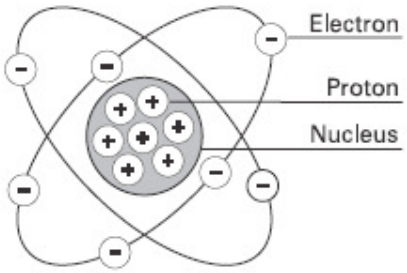
The objectives listed above may sound strange to you. You may also wonder why you would need to know these things to sell Siemens Energy & Automation products. Developing a basic knowledge of electrical concepts, however, will help you to better understand customer applications. In addition, you will be better able to describe products to customers and determine important differences between products.

If you are an employee of a Siemens Energy & Automation authorized distributor, fill out the final exam tear-out card and mail in the card. We will mail you a certificate of completion if you score a passing grade. Good luck with your efforts.

Electron Theory

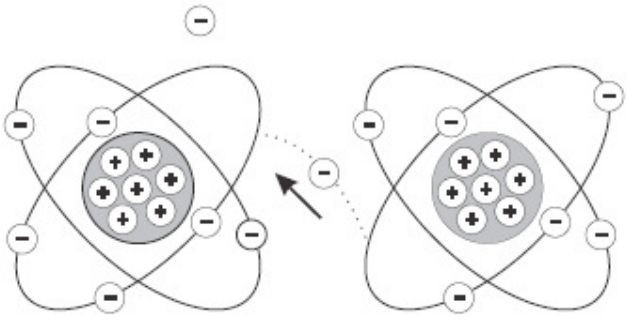
Elements of an atom

All matter is composed of molecules which are made up of a combination of atoms. Atoms have a nucleus with electrons orbiting around it. The nucleus is composed of protons and neutrons (not shown). Most atoms have an equal number of electrons and protons. Electrons have a negative charge (-). Protons have a positive charge (+). Neutrons are neutral. The negative charge of the electrons is balanced by the positive charge of the protons. Electrons are bound in their orbit by the attraction of the protons. These are referred to as bound electrons.



Free electrons

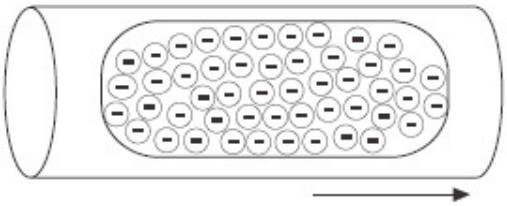
Electrons in the outer band can become free of their orbit by the application of some external force such as movement through a magnetic field, friction, or chemical action. These are referred to as free electrons. A free electron leaves a void which can be filled by an electron forced out of orbit from another atom. As free electrons move from one atom to the next an electron flow is produced. This is the basis of electricity.



Conductors, Insulators and Semiconductors

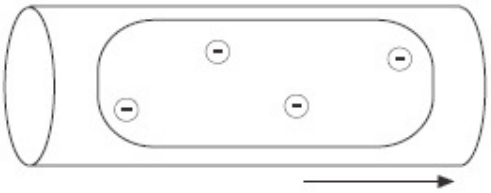
Conductors

An electric current is produced when free electrons move from one atom to the next. Materials that permit many electrons to move freely are called conductors. Copper, silver, aluminum, zinc, brass, and iron are considered good conductors. Copper is the most common material used for conductors and is relatively inexpensive.



Insulators

Materials that allow few free electrons are called insulators. Materials such as plastic, rubber, glass, mica, and ceramic are good insulators.



An electric cable is one example of how conductors and insulators are used. Electrons flow along a copper conductor to provide energy to an electric device such as a radio, lamp, or a motor. An insulator around the outside of the copper conductor is provided to keep electrons in the conductor.

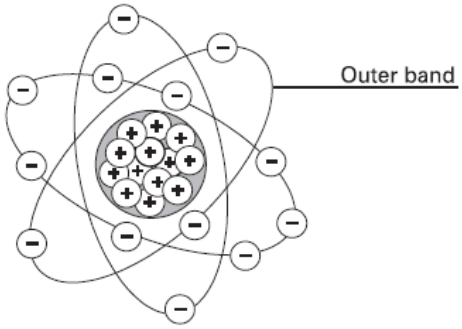
Semiconductors

Semiconductor materials, such as silicon, can be used to manufacture devices that have characteristics of both conductors and insulators. Many semiconductor devices will act like a conductor when an external force is applied in one direction. When the external force is applied in the opposite direction, the semiconductor device will act like an insulator. This principle is the basis for transistors, diodes, and other solid-state electronic device.

Electric Charges

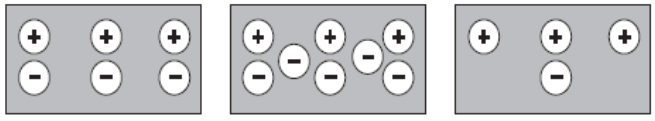
Neutral state of an atom

Elements are often identified by the number of protons in the nucleus of the atoms.
A hydrogen atom, for example, has only one electron and one proton. An aluminum atom (illustrated) has 13 electrons and 13 protons.
An atom with an equal number of electrons and protons is said to be electrically neutral.



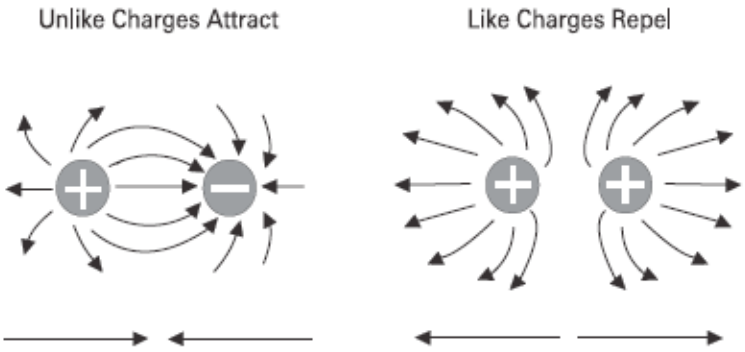
Positive and negative charges

Electrons in the outer band of an atom are easily displaced by the application of some external force. Electrons which are forced out of their orbits can result in a lack of electrons where they leave and an excess of electrons where they come to rest. The lack of electrons is called a positive charge because there are more protons than electrons. The excess of electrons has a negative charge. A positive or negative charge is caused by an absence or excess of electrons. The number of protons remains constant.



Attraction and repulsion of electric charges

The old saying, "opposites attract," is true when dealing with electric charges. Charged bodies have an invisible electric field around them. When two like-charged bodies are brought together, their electric field will work to repel them. When two unlike-charged bodies are brought together, their electric field will work to attract them. The electric field around a charged body is represented by invisible lines of force. The invisible lines of force represent an invisible electrical field that causes the attraction and repulsion. Lines of force are shown leaving a body with a positive charge and entering a body with a negative charge.

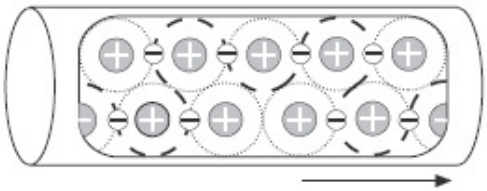


Coulomb's Law

During the 18th century a French scientist, Charles A. Coulomb, studied fields of force that surround charged bodies. Coulomb discovered that charged bodies attract or repel each other with a force that is directly proportional to the product of the charges, and inversely proportional to the square of the distance between them. Today we call this Coulomb's Law of Charges. Simply put, the force of attraction or repulsion depends on the strength of the charged bodies, and the distance between them.

Current

Electricity is the flow of free electrons in a conductor from one atom to the next atom in the same general direction. This flow of electrons is referred to as current and is designated by the symbol "I". Electrons move through a conductor at different rates and electric current has different values. Current is determined by the number of electrons that pass through a cross-section of a conductor in one second. We must remember that atoms are very small. It takes about 1,000,000,000,000,000,000,000,000 atoms to fill one cubic centimeter of a copper conductor. This number can be simplified using mathematical exponents. Instead of writing 24 zeros after the number 1, write 10^{24}. Trying to measure even small values of current would result in unimaginably large numbers. For this reason current is measured in amperes which is abbreviated "amps". The symbol for amps is the letter "A". A current of one amp means that in one second about 6.24×10^{18} electrons move through a cross-section of conductor. These numbers are given for information only and you do not need to be concerned with them. It is important, however, that the concept of current flow be understood.



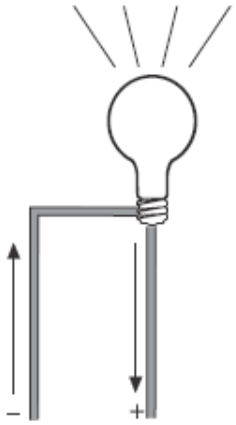
Units of measurement for current

The following chart reflects special prefixes that are used when dealing with very small or large values of current:

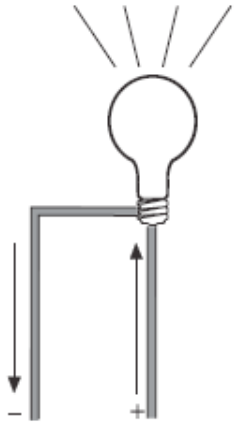
Prefix	Symbol	Decimal
1 kiloampere	1 kA	1000 A
1 milliampere	1 mA	1/1000 A
1 microampere	1 µA	1/1,000,000 A

Direction of current flow

Some authorities distinguish between electron flow and current flow. Conventional current flow theory ignores the flow of electrons and states that current flows from positive to negative. To avoid confusion, this book will use the electron flow concept which states that electrons flow from negative to positive.



Electron Flow

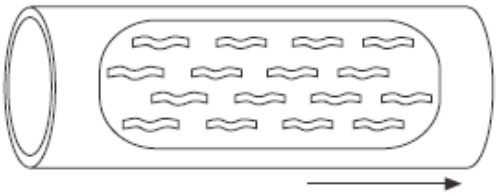


Conventional Current Flow

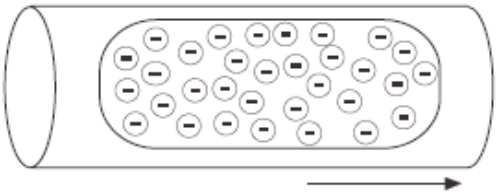
Voltage

Electricity can be compared with water flowing through a pipe. A force is required to get water to flow through a pipe. This force comes from either a water pump or gravity. Voltage is the force that is applied to a conductor that causes electric current to flow.

Water Flow Through a Pipe



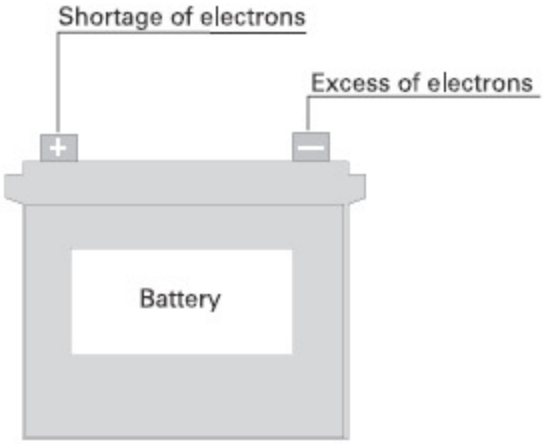
Current Flow Through a Conductor



Electrons are negative and are attracted by positive charges. They will always be attracted from a source having an excess of electrons, thus having a negative charge, to a source having a deficiency of electrons which has a positive charge. The force required to make electricity flow through a conductor is called a difference in potential, electromotive force (emf), or more simply referred to as voltage. Voltage is designated by the letter "E", or the letter "V". The unit of measurement for voltage is volts which is designated by the letter "V".

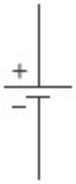
Voltage sources

An electrical voltage can be generated in various ways. A battery uses an electrochemical process. A car's alternator and a power plant generator utilizes a magnetic induction process. All voltage sources share the characteristic of an excess of electrons at one terminal and a shortage at the other terminal. This results in a difference of potential between the two terminals.



Voltage circuit symbol

The terminals of a battery are indicated symbolically on an electrical drawing by two lines. The longer line indicates the positive terminal. The shorter line indicates the negative terminal.



Units of measurement for voltage

The following chart reflects special prefixes that are used when dealing with very small or large values of voltage:

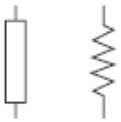
Prefix	Symbol	Decimal
1 kilovolt	1 kV	1000 V
1 millivolt	1 mV	1/1000 V
1 microvolt	1 µV	1/1,000,000 V

Resistance

A third factor that plays a role in an electrical circuit is resistance. All material impedes the flow of electrical current to some extent. The amount of resistance depends upon composition, length, cross-section and temperature of the resistive material. As a rule of thumb, resistance of a conductor increases with an increase of length or a decrease of cross-section. Resistance is designated by the symbol "R". The unit of measurement for resistance is ohms (Ω).

Resistance circuit symbols

Resistance is usually indicated symbolically on an electrical drawing by one of two ways. An unfilled rectangle is commonly used. A zigzag line may also be used.



Resistance can be in the form of various components. A resistor may be placed in the circuit, or the circuit might contain other devices that have resistance.

Units of measurement for resistance

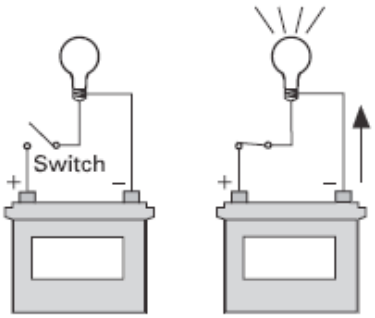
The following chart reflects special prefixes that are commonly used when dealing with values of resistance:

Prefix	Symbol	Decimal
1 kilohm	1 kΩ	1000 Ω
1 megohm	1 MΩ	1,000,000 Ω

Simple Electric Circuit

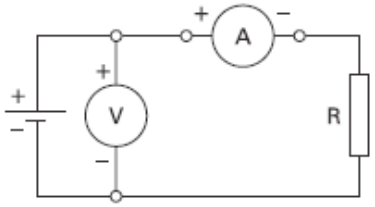
An electric circuit

A fundamental relationship exists between current, voltage, and resistance. A simple electric circuit consists of a voltage source, some type of load, and a conductor to allow electrons to flow between the voltage source and the load. In the following circuit a battery provides the voltage source, electrical wire is used for the conductor, and a light provides the resistance. An additional component has been added to this circuit, a switch. There must be a complete path for current to flow. If the switch is open, the path is incomplete and the light will not illuminate. Closing the switch completes the path, allowing electrons to leave the negative terminal and flow through the light to the positive terminal.



An electrical circuit schematic

The following schematic is a representation of an electrical circuit, consisting of a battery, a resistor, a voltmeter and an ammeter. The ammeter, connected in series with the circuit, will show how much current flows in the circuit. The voltmeter, connected across the voltage source, will show the value of voltage supplied from the battery. Before an analysis can be made of a circuit, we need to understand Ohm's Law.



Review 1

1. List the three basic elements of an atom and state the charge of each (positive, negative, or neutral).

Element	Charge
_____	_____
_____	_____
_____	_____

2. An electron forced out of orbit by an external force is called a _____ _____ .

3. Conductors allow _____ free electrons to flow when an external electric force is applied.

4. Which of the following materials are good conductors?

a.	copper	e.	aluminum
b.	plastic	f.	glass
c.	silver	g.	iron
d.	rubber	h.	mica

5. Semiconductor devices can be manufactured to allow _____ electrons to flow in one direction and _____ electrons to flow in the opposite direction.

Review 2

1. Elements are identified by the number of _____ in the nucleus.
2. A material that has an excess of electrons is said to have a _____ charge.
3. A material that has a deficiency of electrons is said to have a _____ charge.
4. Like charges _____ and unlike charges _____ .
5. The force that is applied to a conductor to cause current flow is _____ .
6. According to the electron flow theory electrons move from
   a. positive to negative
   b. negative to positive
7. With an increase of length or a decrease of cross-section of a conductor, resistance will
   a. increase
   b. decrease

SIEMENS STEP 2000 Self-Study Courses

Homework – Week 1

1) Please read the FLUKE's educational article ***"ABCs of electrical measurement safety"*** and answer the next questions.

a. What does a CAT number refer to?
b. What does the symbol CE indicate?
c. Name one or two American test laboratories that test products for safety and performance compliance

Please, answer the questions in the other side of the page →

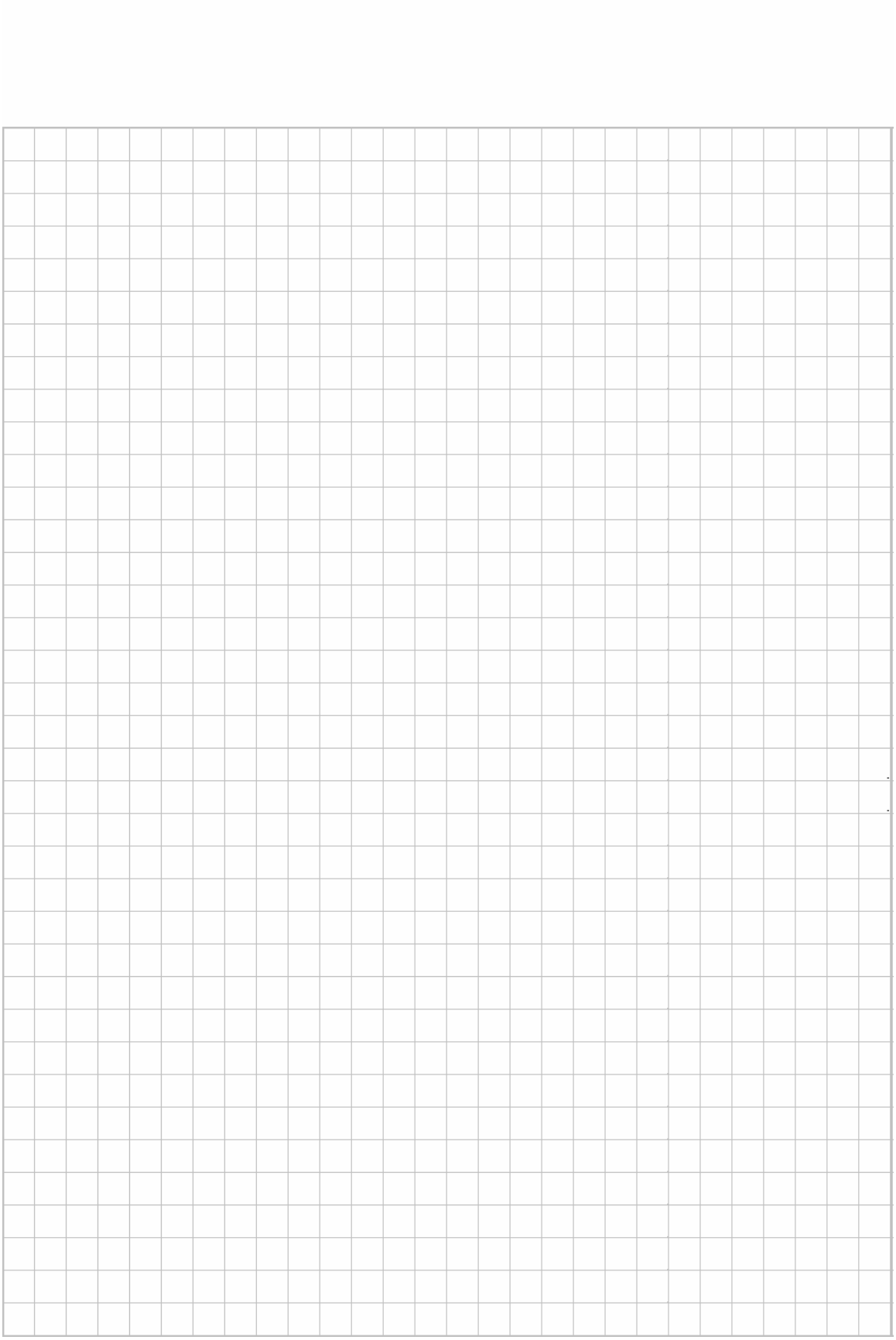
2) Convert units to subunits and vice versa.

	TO	
12 V	→	mV
4 mA	→	A
330 kΩ	→	Ω
$33 \times 10^3 \Omega$	→	MΩ
13.2 kV	→	V
120 mA	→	A
.02 A	→	mA
$47 \times 10^5 \Omega$	→	kΩ
1500 mV	→	V

3) Read the resistance value from the color code

1st band	2nd band	3rd band	4th band	5th band	Value	Tolerance
Red	**Red**	**Brown**	**No band**			
Orange	**Orange**	**Red**	**Red**	**Gold**		
Brown	**Grey**	**Yellow**	**Silver**			
Green	**Blue**	**Red**	**No band**			
Yellow	**Purple**	**Brown**	**Red**			
Blue	**Grey**	**Yellow**	**Silver**			
Brown	**Black**	**Black**	**Gold**			
Orange	**Orange**	**Red**	**Black**	**Brown**		
Red	**Green**	**Silver**	**Brown**			
Green	**Purple**	**Gold**	**Red**			

BLACK BEETLES RUNNING OVER YOUR GARDEN BRING VERY GOOD WEATHER
No band – 20% Silver – 10% Gold – 5% Red – 2% Brown – 1%
Gold 0.1 Silver 0.01



WEEK 2

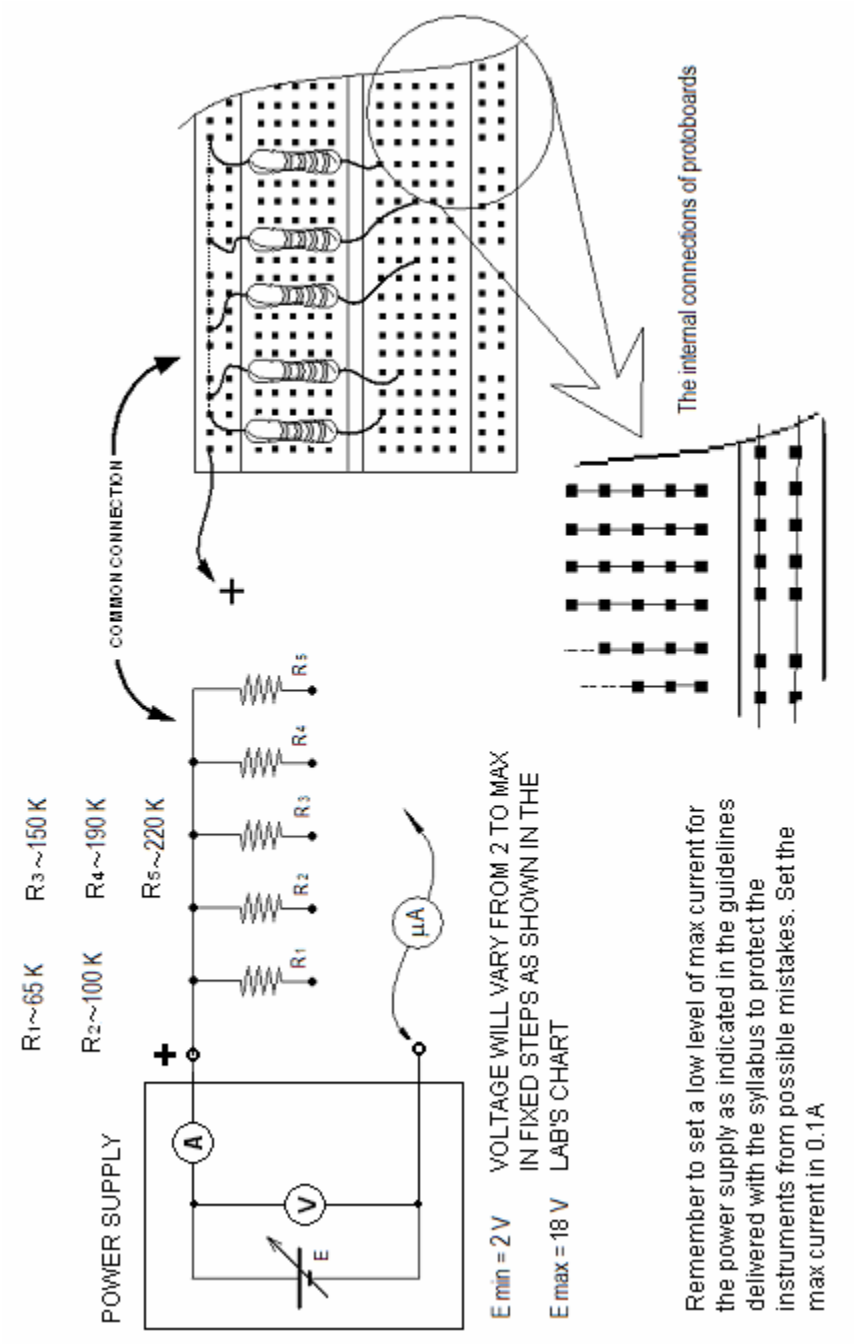
Notes

Notes

Notes

Notes

LAB #2 – OHM's LAW: Using a protoboard put the components as it is shown in the diagram. The ammeter (bench multimeter and/or the power supply's ammeter) will complete circuits with each resistor at different voltage levels. Follow procedures and then record the different values in the chart below


The internal connections of protoboards
COMMON CONNECTION
R1~65 K
R2~100 K
R3~150 K
R4~190 K
R5~220 K
R1
R2
R3
R4
R5
μA
A
V
E
POWER SUPPLY
E min = 2 V
E max = 18 V
VOLTAGE WILL VARY FROM 2 TO MAX IN FIXED STEPS AS SHOWN IN THE LAB'S CHART
Remember to set a low level of max current for the power supply as indicated in the guidelines delivered with the syllabus to protect the instruments from possible mistakes. Set the max current in 0.1A

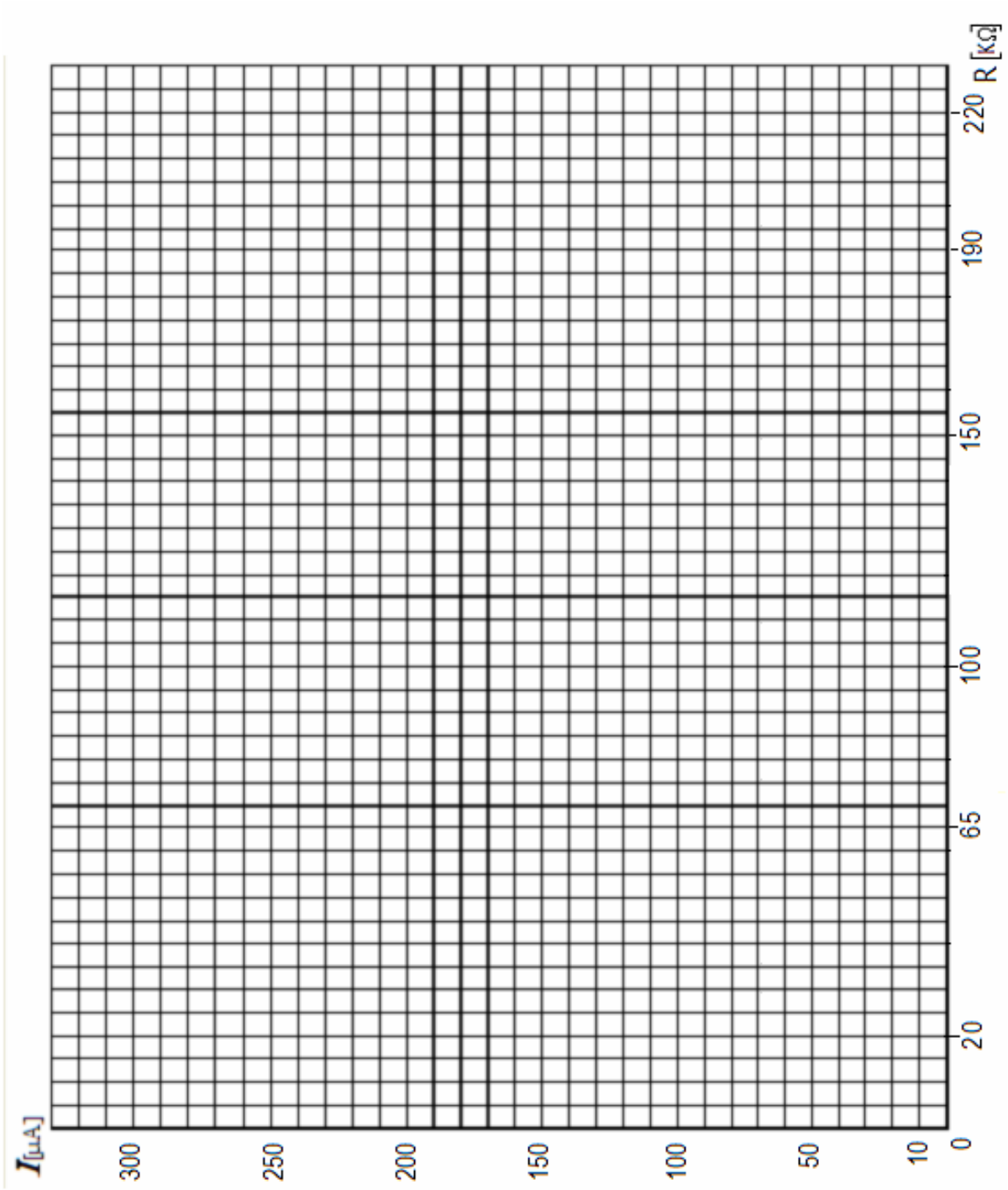
Week 2 **Student name:**_____

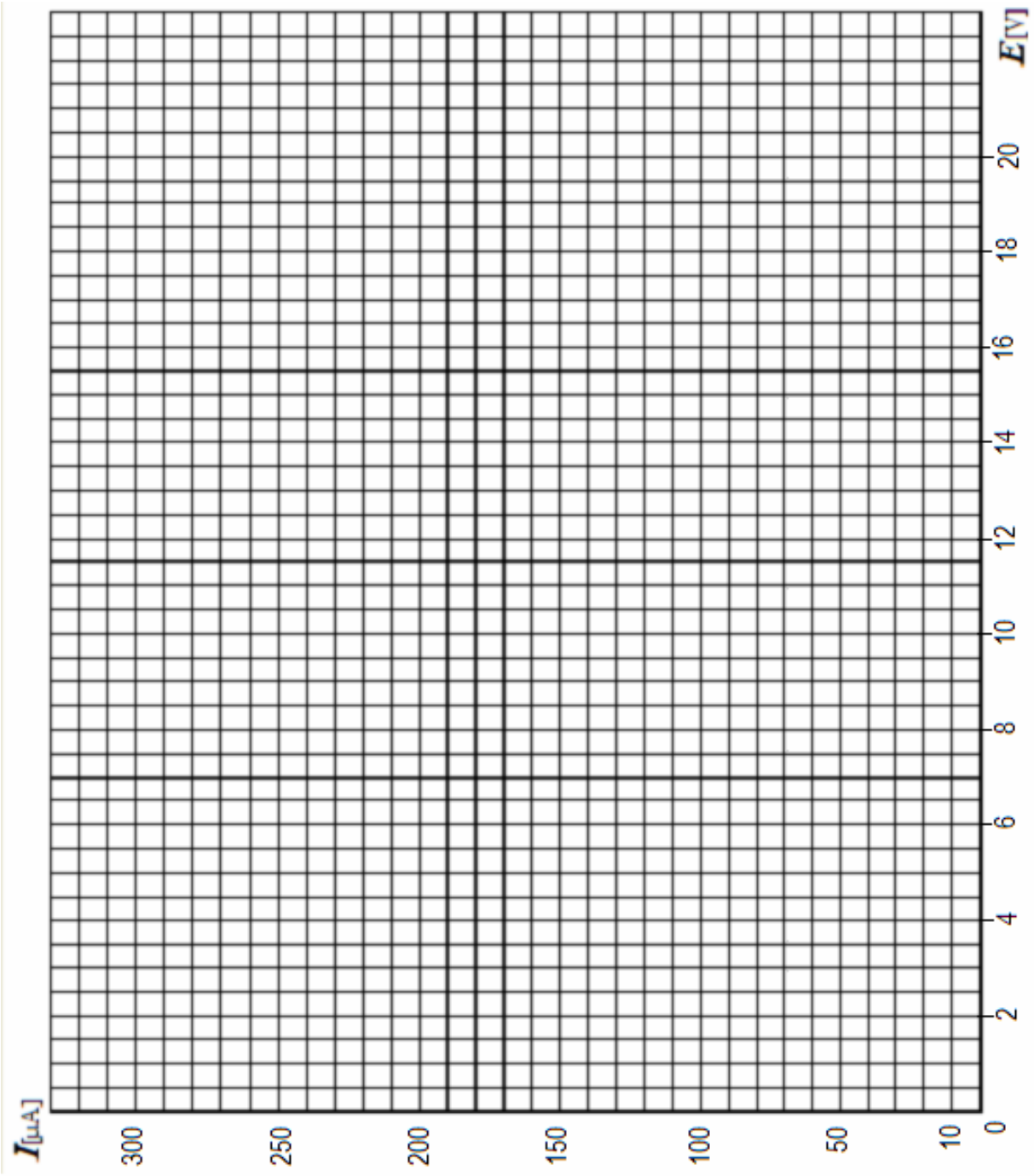
Lab Procedure:

1 Adjust the power supply at the voltage indicated in the first square of each row
2 Complete the circuit with the ammeter by touching with the free meter's lead, the lose end of each resistor
3 Record the reading in the square that correspond with the voltage level and the resistor used for closing a circuit.
4 Repeat 1, 2, and 3 for all the indicated voltage levels

	K	K	K	K	K
2V					
5V					
10V					
12V					
16V					
18V					

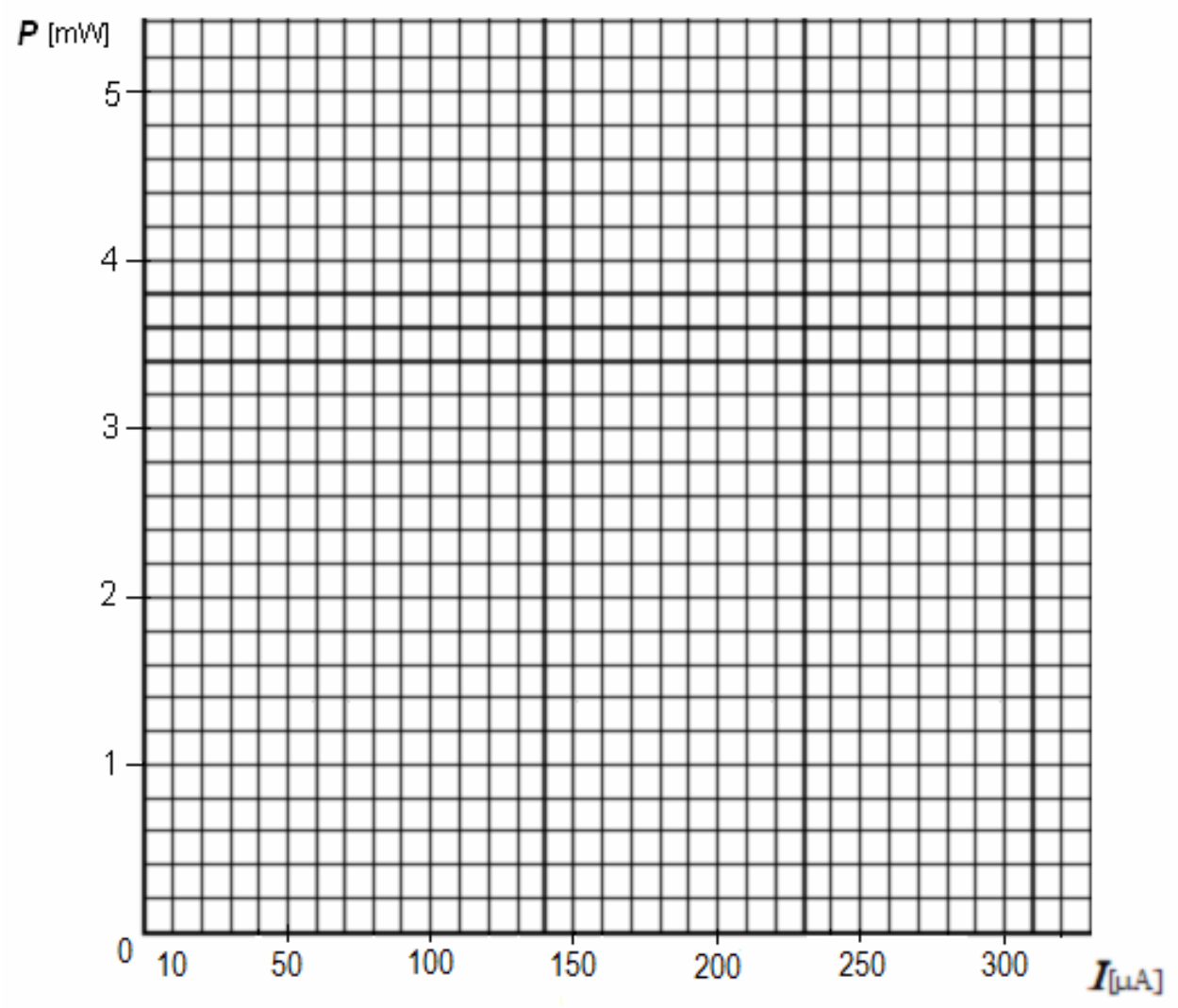
Using the collected data, plot the next graphs – I vs. R, I vs. E, and P vs. I
The first two graphs will show the relation between Current, Resistance, and Voltage. The last graph will show the relation between Power and Current.


R [kΩ]
220
190
150
100
65
20
0
I [μA]
300
250
200
150
100
50
10


E[V]
0
2
4
6
8
10
12
14
16
18
20
I[μA]
300
250
200
150
100
50
10

To chart P vs. I a little more work is required.
Reading along rows is like having a fixed voltage and a variable resistor that steps up from a minimum value to a maximum; as the resistance increases the current decreases in the same proportion. The level of power being developed at each step can be calculated by multiplying each level of current by the voltage. Perform the calculations for the last two voltages levels and plot P vs. I.

16 V	I @ R_1 =	I @ R_2 =	I @ R_3 =	I @ R_4 =	I @ R_5 =
18 V	I @ R_1 =	I @ R_2 =	I @ R_3 =	I @ R_4 =	I @ R_5 =



Ohm's Law

George Simon Ohm and Ohm's Law

The relationship between current, voltage and resistance was studied by the 19th century German mathematician, George Simon Ohm. Ohm formulated a law which states that current varies directly with voltage and inversely with resistance. From this law the following formula is derived:

$$I = \frac{E}{R} \quad \text{or} \quad \text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

Ohm's Law is the basic formula used in all electrical circuits. Electrical designers must decide how much voltage is needed for a given load, such as computers, clocks, lamps and motors. Decisions must be made concerning the relationship of current, voltage and resistance. All electrical design and analysis begins with Ohm's Law. There are three mathematical ways to express Ohm's Law. Which of the formulas is used depends on what facts are known before starting and what facts need to be known.

$$I = \frac{E}{R} \qquad E = I \times R \qquad R = \frac{E}{I}$$

Ohm's Law triangle

There is an easy way to remember which formula to use. By arranging current, voltage and resistance in a triangle, one can quickly determine the correct formula.

Using the triangle

To use the triangle, cover the value you want to calculate. The remaining letters make up the formula.

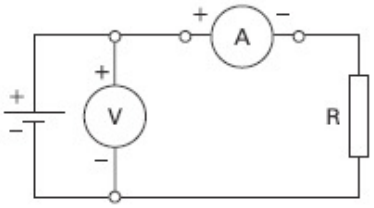
$I = \frac{E}{R}$ $E = I \times R$ $R = \frac{E}{I}$

Ohm's Law can only give the correct answer when the correct values are used. Remember the following three rules:

- Current is always expressed in Amperes or Amps
- Voltage is always expressed in Volts
- Resistance is always expressed in Ohms

Examples of solving Ohm's Law

Using the simple circuit below, assume that the voltage supplied by the battery is 10 volts, and the resistance is 5 Ω.



To find how much current is flowing through the circuit, cover the "I" in the triangle and use the resulting equation.

$$I = \frac{E}{R} \rightarrow I = \frac{10\ volts}{5\ \Omega} \rightarrow I = 2\ amps$$

Using the same circuit, assume the ammeter reads 200 mA and the resistance is known to be 10 Ω. To solve for voltage, cover the "E" in the triangle and use the resulting equation.

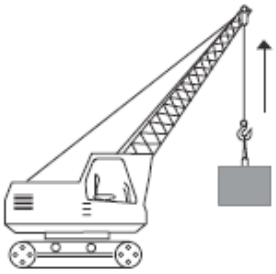
$$E = I \times R \rightarrow E = .2 \times 10 \rightarrow E = 2\ volts$$

Remember to use the correct decimal equivalent when dealing with numbers that are preceded with milli (m), micro (μ) or kilo (k). In this example had 200 been used instead of converting the value to .2, the wrong answer of 2000 volts would have been calculated.

Power

Work

Whenever a force of any kind causes motion, work is accomplished. In the illustration below work is done when a mechanical force is used to lift a weight. If a force were exerted without causing motion, then no work is done.



Electric power

In an electrical circuit, voltage applied to a conductor will cause electrons to flow. Voltage is the force and electron flow is the motion. The rate at which work is done is called power and is represented by the symbol "P". Power is measured in watts and is represented by the symbol "W". The watt is defined *as the rate work is done in a circuit when 1 amp flows with 1 volt applied.*

Power formulas

Power consumed in a resistor depends on the amount of current that passes through the resistor for a given voltage. This is expressed as voltage times current.

$$P = E \times I$$

or

$$P = EI$$

Power can also be calculated by substituting other components of Ohm's Law.

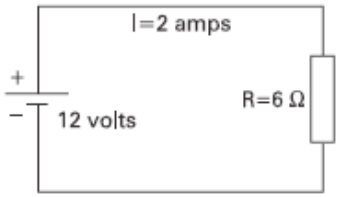
$$P = I^2R$$

and

$$P = \frac{E^2}{R}$$

Solving a power problem

In the following illustration power can be calculated using any of the power formulas.



$$P = EI$$
$$P = 12\ volts \times 2\ amps$$
$$P = 24\ watts$$

$$P = I^2R$$
$$P = (2\ amps)^2 \times 6\ \Omega$$
$$P = 4 \times 6$$
$$P = 24\ watts$$

$$P = \frac{E^2}{R}$$
$$P = \frac{(12\ volts)^2}{6\ \Omega}$$
$$P = \frac{144}{6}$$
$$P = 24\ watts$$

Power rating of equipment

Electrical equipment is rated in watts. This rating is an indication of the rate at which electrical equipment converts electrical energy into other forms of energy, such as heat or light. A common household lamp may be rated for 120 volts and 100 watts. Using Ohm's Law, the rated value of resistance of the lamp can be calculated.

$$P = \frac{E^2}{R} \quad \text{which can be transposed to} \quad R = \frac{E^2}{P}$$
$$R = \frac{(120\ volts)^2}{100\ watts}$$
$$R = 144\ \Omega$$

Using the basic Ohm's Law formula, the amount of current flow for the 120 volt, 100 watt lamp can be calculated.

$$I = \frac{E}{R}$$
$$I = \frac{120\ volts}{144\ \Omega}$$
$$I = .833\ amps$$

A lamp rated for 120 volts and 75 watts has a resistance of 192 Ω and a current of .625 amps would flow if the lamp had the rated voltage applied to it.

$$R = \frac{E^2}{P}$$
$$R = \frac{(120\ volts)^2}{75\ watts}$$
$$R = 192\ \Omega$$

$$I = \frac{E}{R}$$
$$I = \frac{120\ volts}{192\ \Omega}$$
$$I = .625\ amps$$

It can be seen that the 100 watt lamp converts energy faster than the 75 watt lamp. The 100 watt lamp will give off more light and heat.

Heat

Current flow through a resistive material causes heat. An electrical component can be damaged if the temperature is too high. For this reason, electrical equipment is often rated for a maximum wattage. The higher the wattage rating, the more heat the equipment can dissipate.

Problems - OHM's Law

SHOW YOUR WORK – No work, no credit

1) Calculate the current that will flow in a circuit knowing that the voltage applied to it is 60 V and the resistance on the circuit is 300Ω.

↓ Formula

I = ----- = ----- = A ← Solution } Keep format in future problems

↑Variables values

2) How many ohms are necessary to limit to 3A the current in a circuit fed from a 120V outlet

R =

3) Knowing that the heater on a shrinking tunnel has 56Ω and is fed from a 480V line, choose the right fuses from the list: a) 4 A; b) 15 A; c) 8 A; d) 10 A or e) 20 A (the one that has the closest but higher value)

I =

4) What is the resistance of a tungsten filament of a 60 W lamp (when hot); knowing that connected to a 110 V line will draw 545.4 mA?

R =

5) What voltage must be applied to a 1.5 KΩ resistor to make 15 mA circulate through it?

E =

OVER PLEASE →

6) A short to ground is produced in a line fed from a 277 V feeder. From the source to the ground fault there are 100 meters (300 feet). In these 100 meters the resistance of the cable is 2.92Ω. What is the current through the earth connection before the protection trips off?*

I =

Power Basics

1) Calculate the current drained for a lamp of 1000w (when hot) connected to a 120V source.

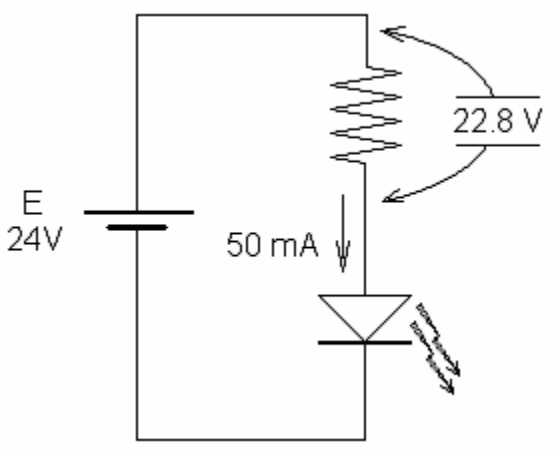
2) Calculate the current drained for a 1000w microwave when is used to full capacity – voltage 120V.

3) Calculate the equivalent in WATTS of 2 ½ HP (1HP = 746W)

* Real short circuits involve **transients** of higher currents than the numbers that come up from direct application of Ohm's law, but in this case we disregard of transients.

4) Calculate the amount of calories an electron flow of 10A will release in a 12Ω resistor in a period of 15 minutes. (1 W = 0.24 cal/sec)

5) Calculate the resistance and wattage of the resistor in the next circuit



WEEK 3

Notes

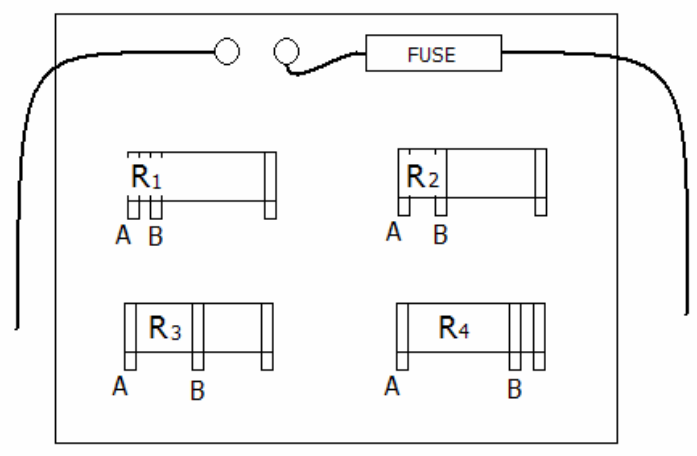
Notes

Notes

Notes

LAB #3 - Kirchoff's Voltage Law – KVL / Series Circuits – Voltage Dividers

Using the board with four industrial type potentiometers, perform connections and measurements as indicated



Using a DMM determine the polarity of the fused lead (+) (-)

Without connecting any load to the power supply, measure the voltage output

E = _____V

Measure potentiometers between points A and B and record their values in the chart bellow

R1	R2	R3	R4

1 Using the provided jumpers with alligators, connect R1 and R2 in series.

2 Measure their combined resistance.

3 Feed them and check voltage across both components and across each component

4 Record your measures in the chart bellow

Series R1 R2	Total Voltage	E_1	E_2

Verify next equations

$$R_S = R_1 + R_2$$ _____

$$E = E_1 + E_2$$ _____

$$\frac{E_1}{E_2} = \frac{R_1}{R_2}$$ _____

If both ratios are equal (or reasonably similar) there is proportionality between numerators as well as denominators.

Do you find proportionality between R1 - E1, and R2 - E2? _____

Check current before R1, between R1 and R2 and after R2 -----

Is it the same? _____ I_a = _____

2nd Part

1 Connect R1 and R3 in series.

2 Measure their combined resistance.

3 Feed them and check voltage across both components and across each component

4 Record your measures in the chart bellow

Series R1 R3	Total Voltage	E_1	E_3

Verify next equations

$R_S = R_1 + R_3$ _____

$E = E_1 + E_3$ _____

$\frac{E_1}{E_3} = \frac{R_1}{R_3}$ _____

Do you find proportionality between R1 - E1, and R3 – E3? _____

Check current before R1, between R1 and R3and after R3 -----

Is it the same? _____ $I_b =$ _____

3rd Part

1 Connect R1 and R4 in series.
2 Measure their combined resistance.
3 Feed them and check voltage across both components and across each component
4 Record your measures in the chart bellow

Series R1 R4	Total Voltage	E_1	E_4

Verify next equations

$R_S = R_1 + R_4$ _____

$E = E_1 + E_4$ _____

$\frac{E_1}{E_4} = \frac{R_1}{R_4}$ _____

Do you find proportionality between R1 - E1, and R4 – E4? _____

Check current before R1, between R1 and R4 and after R4 -----

Is it the same? _____ I_c = _____

1 Which of the three measured current is the highest and say why it is the highest? ____
   a. Ia,
   b. Ib, or
   c. Ic
2 Which of the three measured current is the lowest and say why it is the lowest? ____
   a. Ia,
   b. Ib, or
   c. Ic

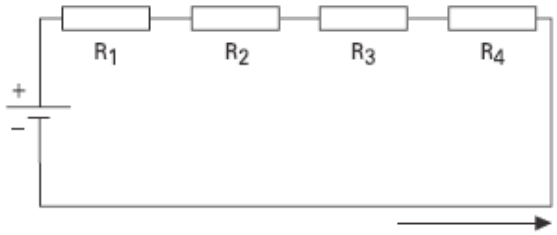
Notice that the highest voltage reading occurred when there was no load connected to the source. This is due to the so-called "load effect."

Power Sources (even excellent ones) have some internal resistivity that appears as a resistor connected in series with the power source. As a consequence some voltage drop occurs inside the device creating heat and reducing the actual output. This is clearly happening in our case since the power supply used to feed the kit is a NON-regulated power supply; which means that there is not internal system to compensate this effect and the voltage output will change with the current demand.

DC Series Circuit

Resistance in a series circuit

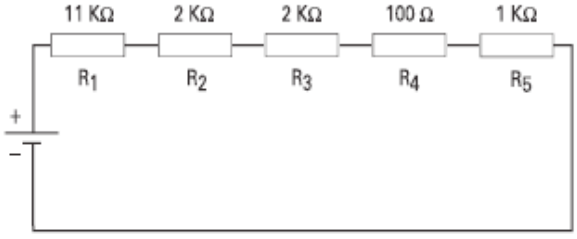
A series circuit is formed when any number of resistors are connected end-to-end so that there is only one path for current to flow. The resistors can be actual resistors or other devices that have resistance. The illustration shows four resistors connected end-to-end. There is one path of current flow from the negative terminal of the battery through R_4, R_3, R_2, R_1 returning to the positive terminal.



Formula for series resistance

The values of resistance add in a series circuit. If a 4 Ω resistor is placed in series with a 6 Ω resistor, the total value will be 10 Ω. This is true when other types of resistive devices are placed in series. The mathematical formula for resistance in series is:

$$R_t = R_1 + R_2 + R_3 + R_4$$



Given a series circuit where R_1 is 11 KΩ, R_2 is 2 KΩ, R_3 is 2 KΩ, R_4 is 100 Ω, and R_5 is 1 KΩ, what is the total resistance?

$$R_t = R_1 + R_2 + R_3 + R_4 + R_5$$
$$R_t = 11{,}000 + 2{,}000 + 2{,}000 + 100 + 1{,}000$$
$$R_t = 16{,}100\ \Omega$$

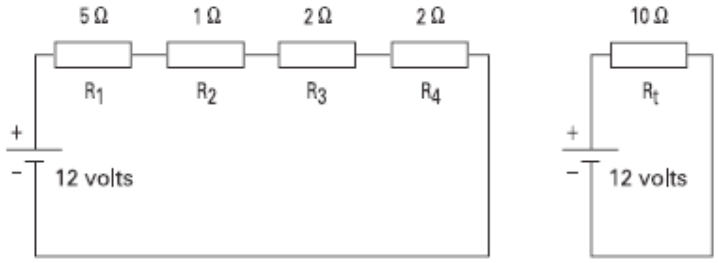
Current in a series circuit

The equation for total resistance in a series circuit allows us to simplify a circuit. Using Ohm's Law, the value of current can be calculated. Current is the same anywhere it is measured in a series circuit.

$$I = \frac{E}{R}$$

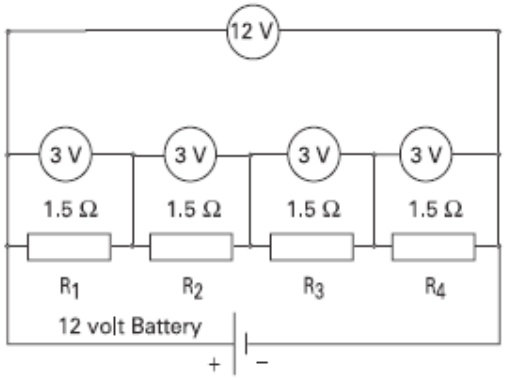
$$I = \frac{12}{10}$$

$$I = 1.2 \text{ amps}$$



Voltage in a series circuit

Voltage can be measured across each of the resistors in a circuit. The voltage across a resistor is referred to as a voltage drop. A German physicist, Kirchhoff, formulated a law which states *the sum of the voltage drops across the resistances of a closed circuit equals the total voltage applied to the circuit*. In the following illustration, four equal value resistors of 1.5 Ω each have been placed in series with a 12 volt battery. Ohm's Law can be applied to show that each resistor will "drop" an equal amount of voltage.



First, solve for total resistance:

$$R_t = R_1 + R_2 + R_3 + R_4$$
$$R_t = 1.5 + 1.5 + 1.5 + 1.5$$
$$R_t = 6\ \Omega$$

Second, solve for current:

$$I = \frac{E}{R}$$
$$I = \frac{12}{6}$$
$$I = 2\ amps$$

Third, solve for voltage across any resistor:

$$E = I \times R$$
$$E = 2 \times 1.5$$
$$E = 3\ volts$$

If voltage were measured across any single resistor, the meter would read three volts. If voltage were read across a combination of R_3 and R_4 the meter would read six volts. If voltage were read across a combination of R_2, R_3, and R_4 the meter would read nine volts. If the voltage drops of all four resistors were added together the sum would be 12 volts, the original supply voltage of the battery.

Voltage division in a series circuit

It is often desirable to use a voltage potential that is lower than the supply voltage. To do this, a voltage divider, similar to the one illustrated, can be used. The battery represents E_{in} which in this case is 50 volts. The desired voltage is represented by E_{out} which mathematically works out to be 40 volts. To calculate this voltage, first solve for total resistance.

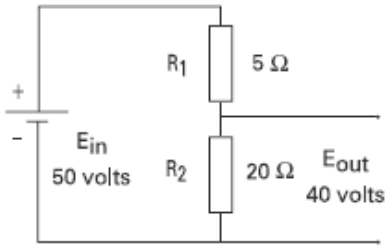
$$R_t = R_1 + R_2$$
$$R_t = 5 + 20$$
$$R_t = 25\ \Omega$$

Second, solve for current:

$$I = \frac{E_{in}}{R_t}$$
$$I = \frac{50}{25}$$
$$I = 2\ amps$$

Finally, solve for voltage:

$$E_{out} = I \times R_2$$
$$E_{out} = 2 \times 20$$
$$E_{out} = 40\ volts$$



STEP 2000
Self-Study Courses
SIEMENS

Review 3

1. The basic Ohm's Law formula is _____ .

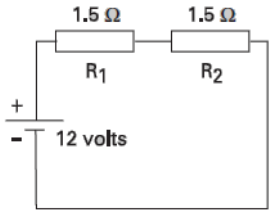
2. When solving circuit problems; current must always be expressed in _____ , voltage must always be expressed in _____ and resistance must always be expressed in _____ .

3. The total current of a simple circuit with a voltage supply of 12 volts and a resistance of 24 Ω is _____ amps.

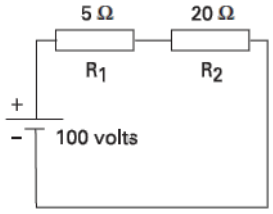
4. What is the total resistance of a series circuit with the following values: $R_1 = 10\,\Omega$, $R_2 = 15\,\Omega$, and $R_3 = 20\,\Omega$? _____ Ω .

5. What is total current of a series circuit that has a 120 volt supply and 60 Ω resistance?

6. In the following circuit the voltage dropped across R_1 is _____ volts and R_2 is _____



7. In the following circuit voltage dropped across R_1 is _____ volts, and R_2 is _____ volts.

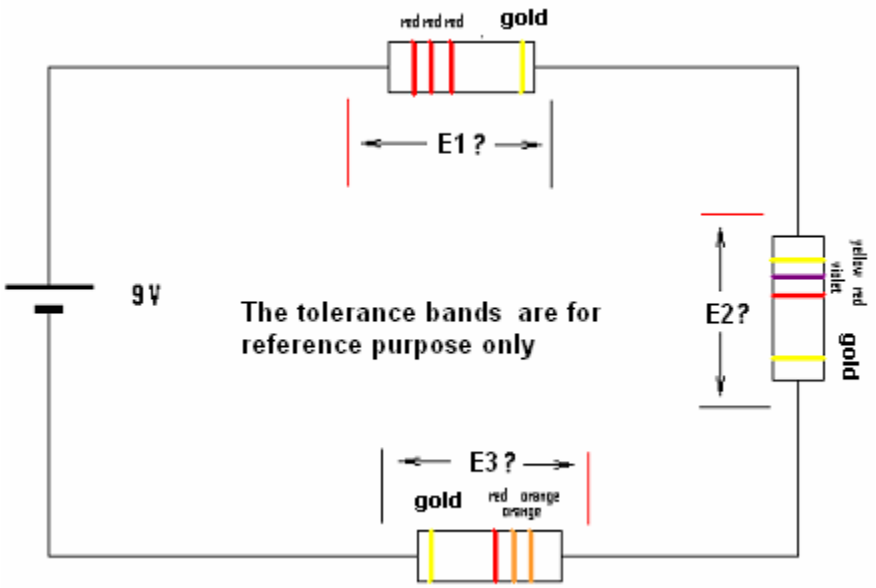


Problems – Series Circuits – SHOW YOUR WORK !!!

S.1

a) Find E1, E2 and E3.

b) Verify, KVL, Voltage Divider formula, and voltage drop-resistors proportionality



The next chart gives orientation about the order of logical steps to be taken to solve this problem

R1	Red – Red – Red		
R2	Yellow – Violet – Red		
R3	Orange – Orange – Red		
Rt			
Using OHM's Law: I			
Using OHM's Law: E1			
Using OHM's Law: E2			
Using OHM's Law: E3			

OVER PLEASE →

KVL	E =		
Voltage Divider Formula	E1 =		
	E2 =		
	E3 =		

Voltage drop-resistor proportionality	R1/R2			E1/E2

What is a "Voltage Divider"?

It is a SERIES CIRCUIT!!! Check in this manual at the end of week 3 reading material: "Voltage division in a Series Circuit"

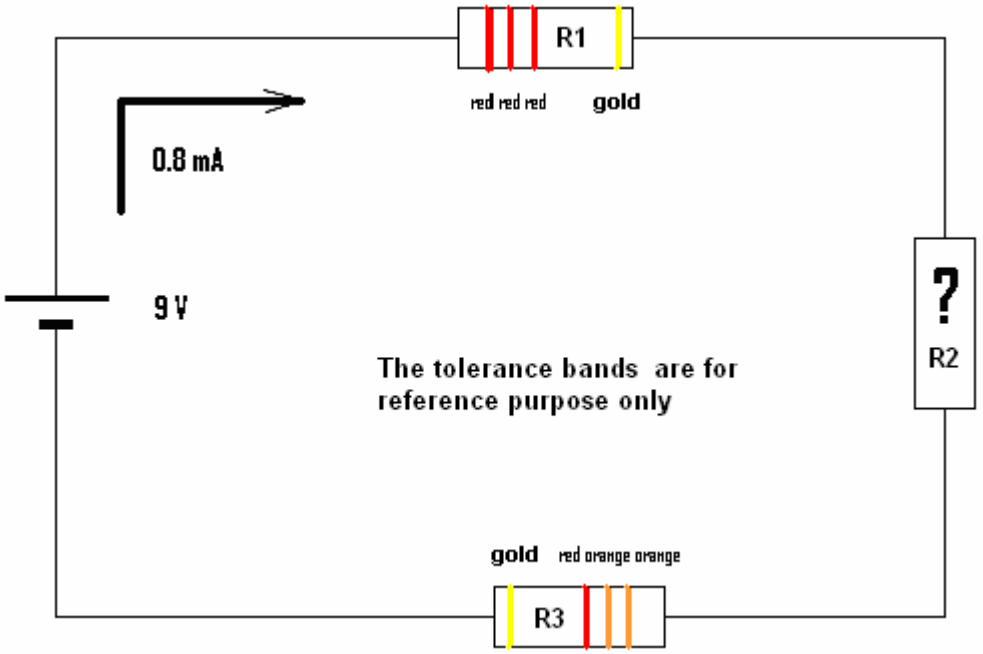
The "Voltage Divider Formula" is a shortcut. The following formula is its general expression

$$E_y = \frac{E_T}{R_T} \times R_y$$

Ey is any voltage drop in a series circuit.
Ry is the particular resistor that produces the voltage drop Ey.
Et/Rt is the total current
In summary, the "Voltage Divider Formula" is the successive application of ohm's law. First calculate the total current (the voltage applied divided by the addition of all the resistors in the series), and then multiply by the resistor that produces the voltage drop.

S.2

a) Find R2
b) Verify KVL, Voltage Divider formula and voltage drop- resistors proportionality
c) Define color bands for R2 in a 4 band code system if its resistance value is define within 5% tolerance



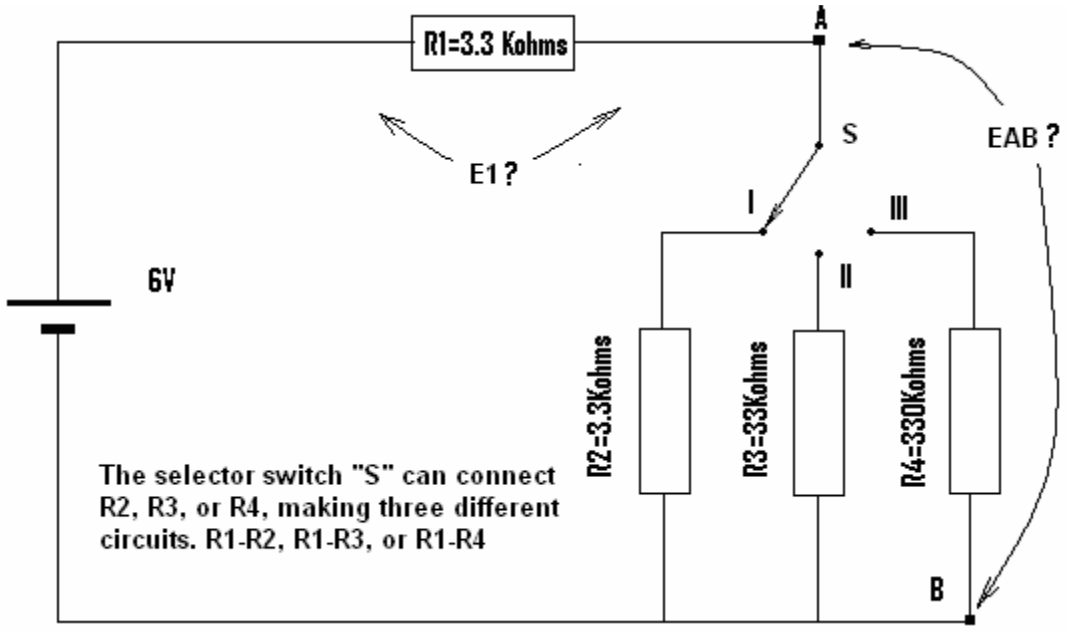
R1		Red – Red – Red			
R3		Orange – Orange – Red			
OHM's Law	Rt				
R2					
		1st Band	2nd Band	3rd Band	4th Band

OVER PLEASE →

KVL	E =			
Voltage Divider Formula	E1 =			
	E2 =			
	E3 =			
Voltage drop-resistor proportionality	R1/R2			E1/E2

S.3
Imagine switching S between positions I, II and III, and complete the next table – Plan your work and work your plan – SHOW YOUR WORK – BE METHODIC!!! There is not a chart to guide your work, so take as example the methodology followed in S.1 and S.2

Position	E1	EAB
I	V	V
II	V	V
III	V	V



WEEK 4

Notes

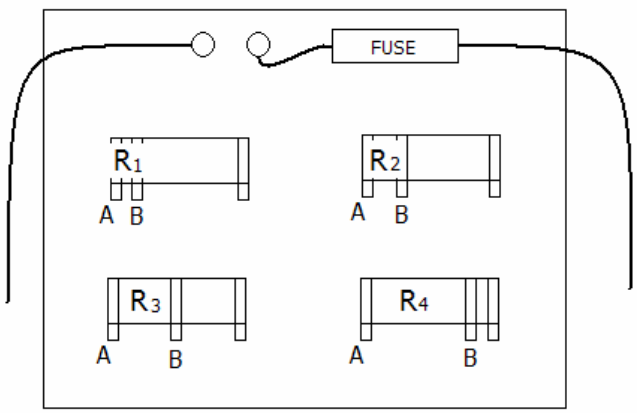
Notes

Notes

Notes

LAB #4 - Kirchoff's Current Law - Parallel Circuits - Current Dividers

Using the same set of four industrial potentiometers you have used for the circuits lab, perform the next tasks:



series

1) Connect R1 and R2 in parallel

Measure their combined resistance.
Feed them and check current through both components and through each component
Record your measures in the chart bellow

Parallel R1 R2	Total Current	I_1	I_2

Verify next equations

$$R_P = \frac{R_1 * R_2}{R_1 + R_2}$$ _____

$$I = I_1 + I_2$$ _____

$$\frac{I_1}{I_2} = \frac{R_2}{R_1}$$ _____

Do you find proportionality between R1 – I2, and R2 – I1? ☐Yes, the ratios are close ☐ Not at all

Notice that now there is an **INVERSE** proportionality.

Check voltage across R1 and across R2

Are they the same? ☐Yes, very close ☐ Not at all

2) Connect R1 and R3 in parallel

Measure their combined resistance.
Feed them and check current through both components and through each component
Record your measures in the chart bellow

Parallel R1 R3	Total Current	I_1	I_3

Verify next equations

$$R_P = \frac{R_1 * R_3}{R_1 + R_3}$$ _____

$$I = I_1 + I_3$$ _____

$$\frac{I_1}{I_3} = \frac{R_3}{R_1}$$ _____

Do you find proportionality between R1 – I3, and R3 – I1? ☐Yes, the ratios are close ☐ Not at all

Check voltage across R1 and across R3

Are they the same? ☐Yes, very close ☐ Not at all

3) Connect R1 and R4 in parallel

Measure their combined resistance.
Feed them and check current through both components and through each component
Record your measures in the chart bellow

Parallel R1 R4	Total Current	I_1	I_4

Verify next equations

$$R_P = \frac{R_1 * R_4}{R_1 + R_4}$$ _____

$$I = I_1 + I_4$$ _____

$$\frac{I_1}{I_4} = \frac{R_4}{R_1}$$ _____

Do you find proportionality between *R1 – I4*, and *R4 – I1*? ☐Yes, the ratios are close ☐ Not at all

Check voltage across *R1* and across *R4*

Are they the same? ☐Yes, very close ☐ Not at all

A) Did I_1 change significantly along the three experiments? (20% or more) YES – NO

B) Which case did render the largest *It*?

- ☐ Experiment 1 – R1 in parallel with R2
- ☐ Experiment 2 – R1 in parallel with R3
- ☐ Experiment 3 – R1 in parallel with R4

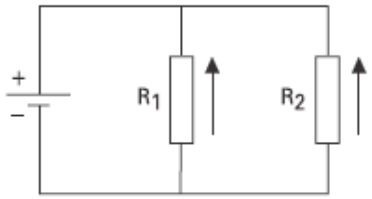
C) Why do you think it was the reason?

Items A, B and C will discussed in class after Lab #4

DC Parallel Circuit

Resistance in a parallel circuit

A parallel circuit is formed when two or more resistances are placed in a circuit side-by-side so that current can flow through more than one path. The illustration shows two resistors placed side-by-side. There are two paths of current flow. One path is from the negative terminal of the battery through R_1 returning to the positive terminal. The second path is from the negative terminal of the battery through R_2 returning to the positive terminal of the battery.



Formula for equal value resistors in a parallel circuit

To determine the total resistance when resistors are of equal value in a parallel circuit, use the following formula:

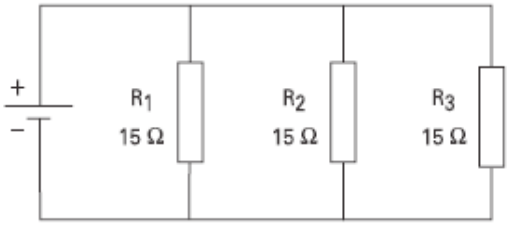
$$R_t = \frac{Value\ of\ any\ one\ resistor}{Number\ of\ resistors}$$

In the following illustration there are three 15 Ω resistors. The total resistance is:

$$R_t = \frac{Value\ of\ any\ one\ resistor}{Number\ of\ resistors}$$

$$R_t = \frac{15}{3}$$

$$R_t = 5\ \Omega$$



Formula for unequal resistors in a parallel circuit

There are two formulas to determine total resistance for unequal value resistors in a parallel circuit. The first formula is used when there are three or more resistors. The formula can be extended for any number of resistors.

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

In the following illustration there are three resistors, each of different value. The total resistance is:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

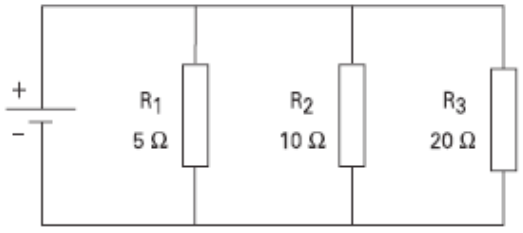
$$\frac{1}{R_t} = \frac{1}{5} + \frac{1}{10} + \frac{1}{20} \qquad \textit{Insert value of the resistors}$$

$$\frac{1}{R_t} = \frac{4}{20} + \frac{2}{20} + \frac{1}{20} \qquad \textit{Find lowest common denominator}$$

$$\frac{1}{R_t} = \frac{7}{20} \qquad \textit{Add the numerators}$$

$$\frac{R_t}{1} = \frac{20}{7} \qquad \textit{Invert both sides of the equation}$$

$$R_t = 2.86\ \Omega \qquad \textit{Divide}$$

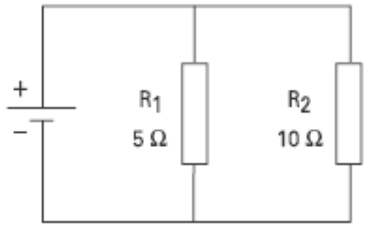


The second formula is used when there are only two resistors.

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

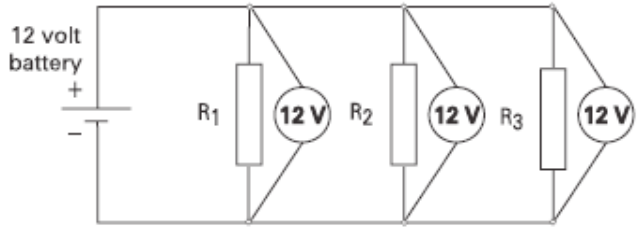
In the following illustration there are two resistors, each of different value. The total resistance is:

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$
$$R_t = \frac{5 \times 10}{5 + 10}$$
$$R_t = \frac{50}{15}$$
$$R_t = 3.33\ \Omega$$



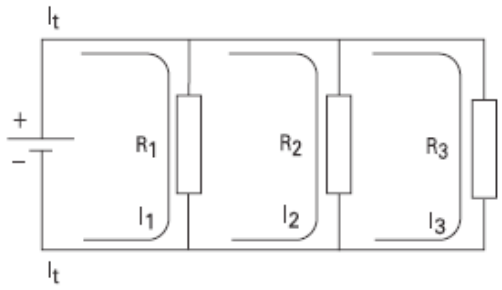
Voltage in a parallel circuit

When resistors are placed in parallel across a voltage source, the voltage is the same across each resistor. In the following illustration three resistors are placed in parallel across a 12 volt battery. Each resistor has 12 volts available to it.



Current in a parallel circuit

Current flowing through a parallel circuit divides and flows through each branch of the circuit.

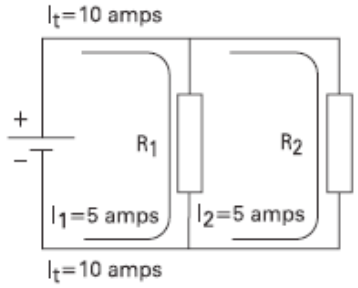


Total current in a parallel circuit is equal to the sum of the current in each branch. The following formula applies to current in a parallel circuit:

$$I_t = I_1 + I_2 + I_3$$

Current flow with equal value resistors in a parallel circuit

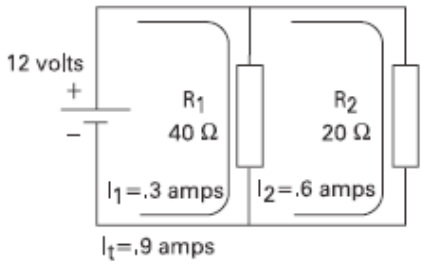
When equal resistances are placed in a parallel circuit, opposition to current flow is the same in each branch. In the following circuit R_1 and R_2 are of equal value. If total current (I_t) is 10 amps, then 5 amps would flow through R_1 and 5 amps would flow through R_2.



$$I_t = I_1 + I_2$$
$$I_t = 5\ amps + 5\ amps$$
$$I_t = 10\ amps$$

Current flow with unequal value resistors in a parallel circuit

When unequal value resistors are placed in a parallel circuit, opposition to current flow is not the same in every circuit branch. Current is greater through the path of least resistance. In the following circuit R_1 is 40 Ω and R_2 is 20 Ω. Small values of resistance means less opposition to current flow. More current will flow through R_2 than R_1.



Using Ohm's Law, the total current for each circuit can be calculated.

$$I_1 = \frac{E}{R_1}$$
$$I_1 = \frac{12\ volts}{40\ \Omega}$$
$$I_1 = .3\ amps$$

$$I_2 = \frac{E}{R_2}$$
$$I_2 = \frac{12\ volts}{20\ \Omega}$$
$$I_2 = .6\ amps$$

$$I_t = I_1 + I_2$$
$$I_t = .3\ amps + .6\ amps$$
$$I_t = .9\ amps$$

Total current can also be calculated by first calculating total resistance, then applying the formula for Ohm's Law.

$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_t = \frac{40\ \Omega \times 20\ \Omega}{40\ \Omega + 20\ \Omega}$$

$$R_t = \frac{800\ \Omega}{60\ \Omega}$$

$$R_t = 13.333\ \Omega$$

$$I_t = \frac{E}{R_t}$$

$$I_t = \frac{12\ volts}{13.333\ \Omega}$$

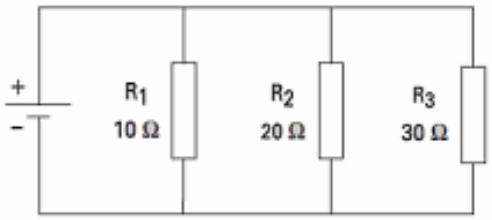
$$I_t = .9\ amps$$

STEP 2000
Self-Study Courses
SIEMENS

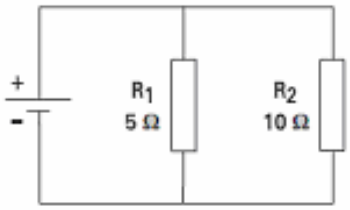
Review 4

1. The total resistance of a parallel circuit that has four 20 Ω resistors is _____ Ω.

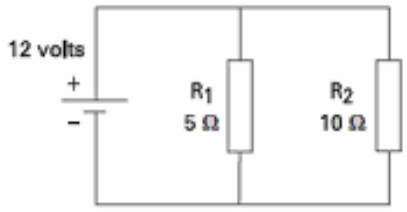
2. R_t for the following circuit is _____ Ω.



3. R_t for the following circuit is _____ Ω.

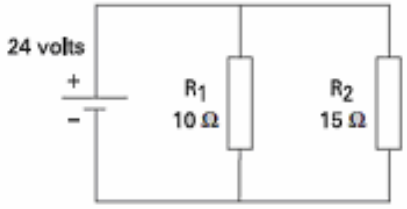


4. Voltage available at R_2 in the following circuit is _____ volts.



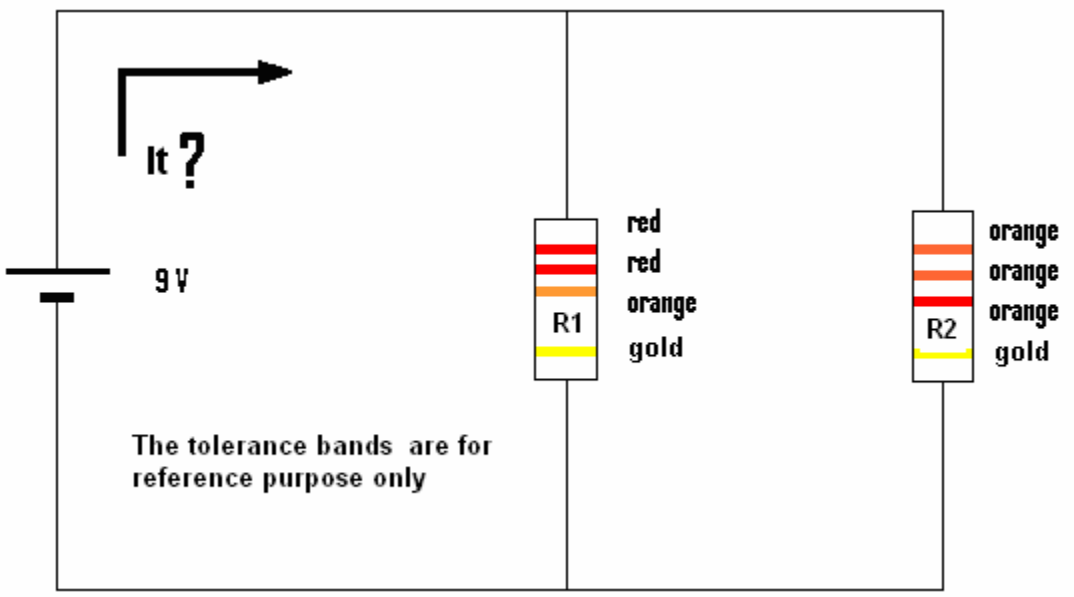
5. In a parallel circuit with two resistors of equal value and a total current flow of 12 amps, the value of current through each resistor is _____ amps.

6. In the following circuit current flow through R_1 is _____ amps, and R_2 is _____ amps.



Problems – Parallel Circuits SHOW YOUR WORK!!!

P.1 a) Find It (total current) that is being drained from the battery
b) Verify Current Divider formula and Branch currents – Resistors inverse proportionality



Method 1

R1		Red – Red – Orange		
R2		Orange – Orange - Orange		
Rt				
OHM's Law	It			

Method 2

OHM's Law	I1			
	I2			
KCL	It			

OVER PLEASE →

Current Divider Formula	I1			
	I2			
Branch currents – Resistors inverse proportionality	R1/R2		I2/I1	
	R2/R1		I1/I2	

What is a "Current Divider"? It is a PARALLEL CIRCUIT!!!
The "Current Divider Formula" is a shortcut. The following formula is its general expression

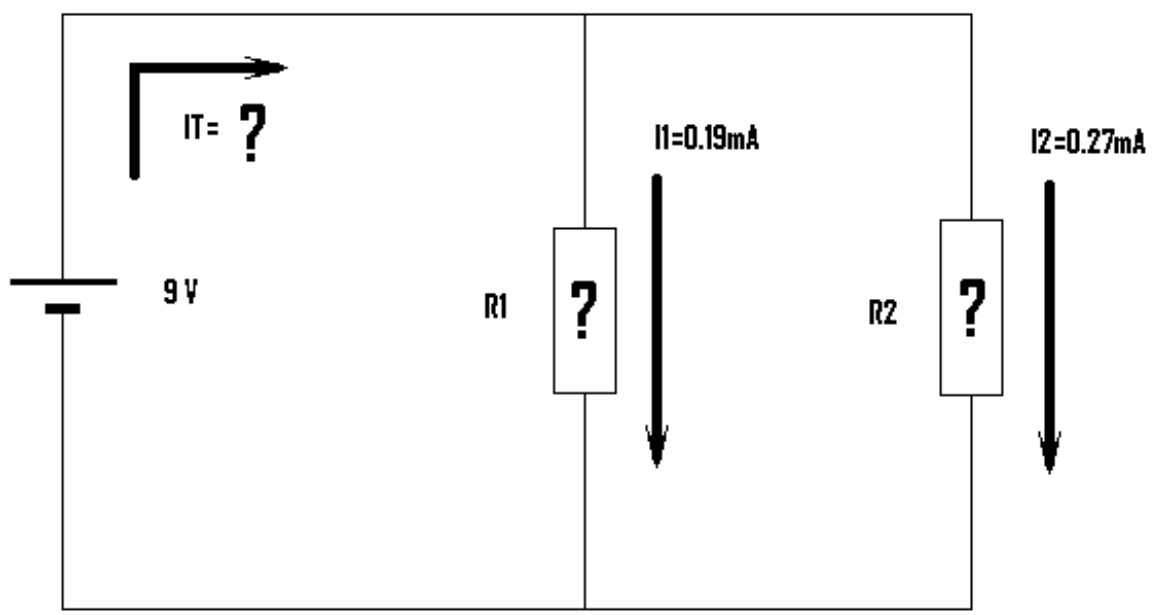
$$I_y = \frac{I_T \times R_p}{R_y}$$

Iy is any branch current in a parallel circuit.
Ry is the particular resistor that is draining *Iy*.
It x Rp is the voltage applied to the parallel

In summary, the "Current Divider Formula" is the successive application of Ohm's law.
First calculate the voltage across the parallel (the current entering in the parallel multiplied by the total resistance of the parallel), and then divide by the resistor that drains the branch current.

P.2

a) Find It, R1, and R2
b) Verify Current Divider formula and Branch's currents – Resistors ratios
c) Define color bands for R1 and R2 in a 5 band code system if their resistance is defined within 2% tolerance.



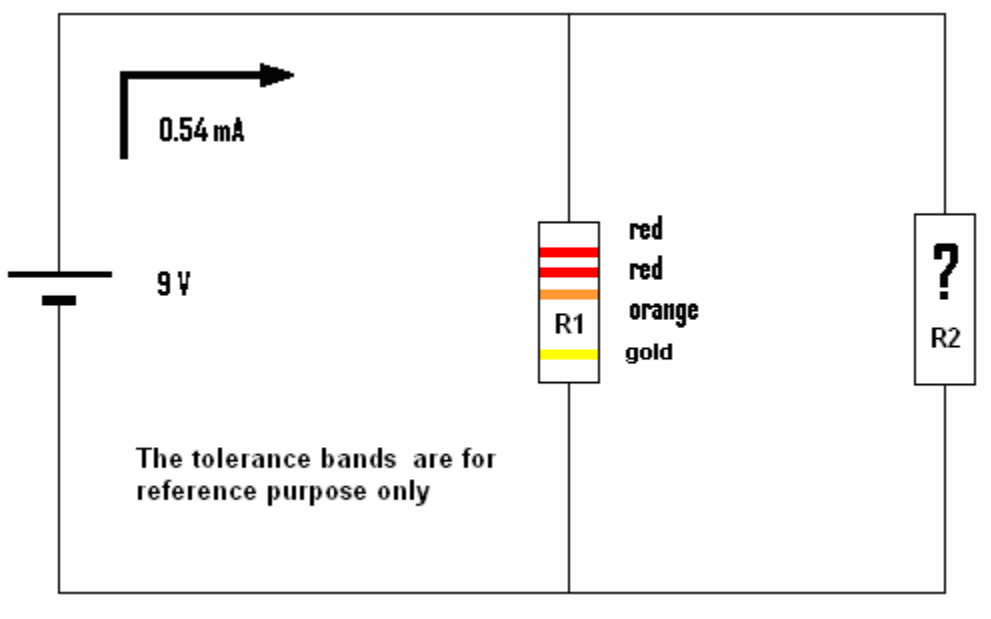
KCL	It					
OHM's Law	R1					
		1st Band	2nd Band	3rd Band	4th Band	5th Band
	R2					
		1st Band	2nd Band	3rd Band	4th Band	5th Band

OVER PLEASE →

Current Divider Formula	I1			
	I2			
Branch currents – Resistors inverse proportionality	R1/R2		I2/I1	
	R2/R1		I1/I2	

P.3

Calculate R2



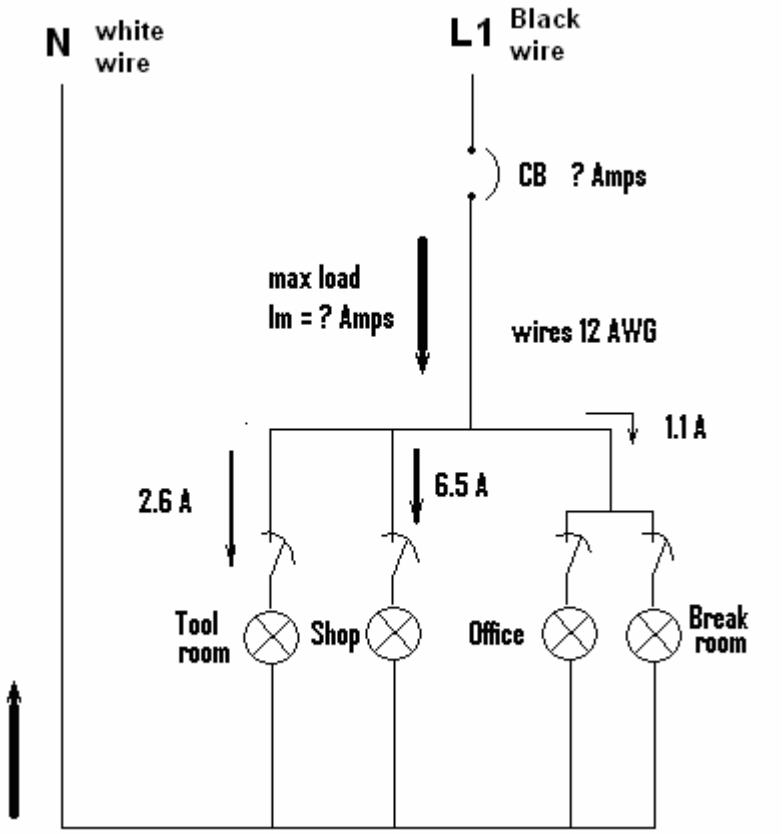
P.4

The next schematic shows a distribution configuration of light fixtures for a wood shop; the whole installation is made with wire size 12 AWG (20 A).

Calculate:

a) The current in the main feeder when all lights are ON

b) Knowing that the circuit breaker (CB) must open when the current flowing through it exceeds the amps that are safe for the wire select the appropriate CB to protect the circuit's wires from the list 1) 10 A, 2) 15 A or 3) 25 A. (select the closer CB to 1.25 times the max load current Im – ask your instructor for NEC's continuous loads previsions)



Im		
CB amp rating		

WEEK 5

Notes

Notes

Notes

Notes

LAB #5 - Kirchoff's Laws – Series-Parallel circuits

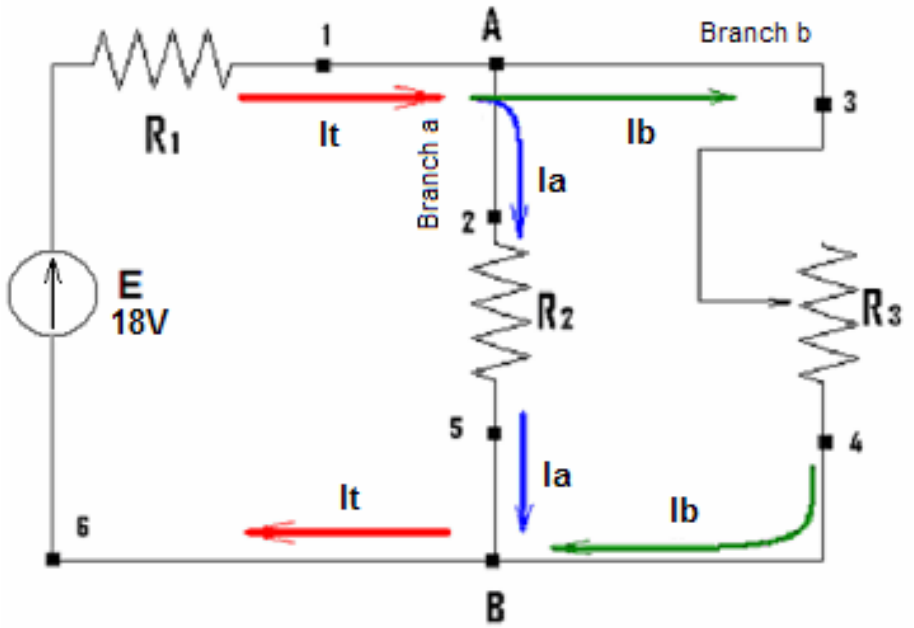
Please read the next paragraph and then build the circuit shown below in your protoboard.

The circuit has 6 connection points beside the nodes A and B. These connection points are named 1, 2, 3, 4, 5 and 6. Between point 1 and node A there is a wire; we call it a "jumper". There are jumpers also between node A and point 2, A and 3, 4 and B, 5 and B, and the last one between node B and point 6. By removing any of these jumpers, an amp-meter can be introduced into the circuit.

These are the circuit's components:

R1 = 10K;
R2 = 10K and
R3 = variable resistor of 100K.

Identify the component from the provided elements. Please check the true value of R1 and R2. Set R3 as close as possible to 5K. Record their resistances in the next chart and then build the circuit



R1	R2	R3

Copy and keep this schematic at sight.

Perform the next six current measurements, record these readings and identify each current.

Current between	mA reading	Current name
1-A		
A-2		
A-3		
4-B		
5-B		
B-6		

Please verify KCL

It = Ia + Ib _____

Ia + Ib = It _____

Perform the next voltage measurements and record these readings

Voltage between	V reading
At the source	
Across R1	
A-B	
2-5	
3-4	
1-6	
1-B	
1-5	
1-4	

Please verify KVL

E = E1 + E_{AB} _____

Are the last seven readings the same? YES NO

Why? _____

The next chart demands the performing of 63 measurements of current, voltage and resistance. When it is completed, it will give a sort of "picture" how compound circuits behave.

Set R3 as close as possible to the indicated value in the first column. Perform the required measurements. Try to obtain the best possible reading. Do not forget to indicate units.
For the last two rows R3 will remain constant and R1 will change. Please follow further instruction in one of the last rows

R3		R		Ia	Ib	It	E_1	E_{AB}	E (source)
Setting	True value	R_{AB}	Rt						
500 Ω									
5000 Ω									
10000 Ω									
20000 Ω									
100 KΩ									
Instruction: Keep R3 at its maximum value (close to 100K) and replace R1 for the other provided potentiometer. Adjust R1 as indicated and perform the required measurements									
R1		R		Ia	Ib	It	E_1	E_{AB}	E (source)
Setting	True value	R_{AB}	Rt						
20000 Ω									
100 KΩ									

Calculator time!!!

Based on your Ω, Amps, and Volts readings complete the next chart.

R3 true setting	R2 true value	$\frac{R2 \times R3}{R2 + R3}$	R1 true value	$R1 + \frac{R2 \times R3}{R2 + R3}$	$\frac{EAB}{It}$	$\frac{E}{It}$

It X Rt							
E / Rt							
E1 + E_{AB}							
Ia + Ib							

Magic time!!!

Orderly transcript from the charts above (readings and calculation) the data required in the charts below.

R_{AB}	$\frac{R2 \times R3}{R2 + R3}$	$\frac{E_{AB}}{I_t}$

R_t	$R1 + \frac{R2 \times R3}{R2 + R3}$	$\frac{E}{I_t}$

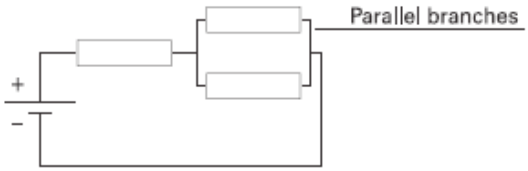
It X Rt							
E1 + E_{AB}							
E							

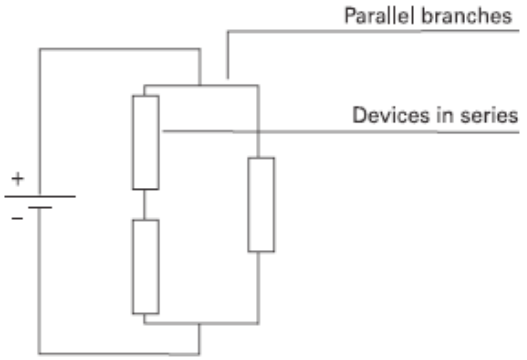
$\frac{E}{Rt}$							
Ia + Ib							
It							

Conclusions for this lab will be discussed in class

Series-Parallel Circuits

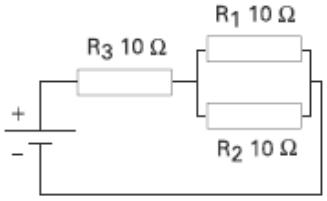
Series-parallel circuits are also known as compound circuits. At least three resistors are required to form a series-parallel circuit. The following illustrations show two ways a series-parallel combination could be found.





Simplifying a series-parallel circuit to a series circuit

The formulas required for solving current, voltage and resistance problems have already been defined. To solve a series-parallel circuit, reduce the compound circuits to equivalent simple circuits. In the following illustration R_1 and R_2 are parallel with each other. R_3 is in series with the parallel circuit of R_1 and R_2.



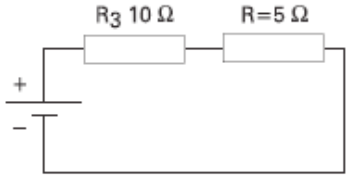
First, use the formula to determine total resistance of a parallel circuit to find the total resistance of R_1 and R_2. When the resistors in a parallel circuit are equal, the following formula is used:

$$R = \frac{\textit{Value of any one resistor}}{\textit{Number of resistors}}$$

$$R = \frac{10\ \Omega}{2}$$

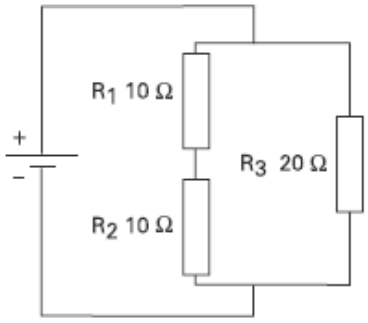
$$R = 5\ \Omega$$

Second, redraw the circuit showing the equivalent values. The result is a simple series circuit which uses already learned equations and methods of problem solving.



Simplifying a series-parallel circuit to a parallel circuit

In the following illustration R_1 and R_2 are in series with each other. R_3 is in parallel with the series circuit of R_1 and R_2.



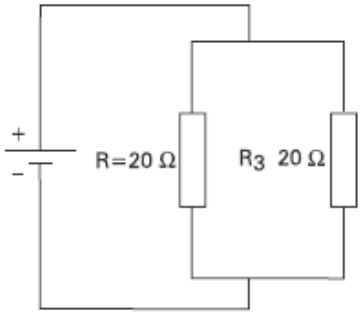
First, use the formula to determine total resistance of a series circuit to find the total resistance of R_1 and R_2. The following formula is used:

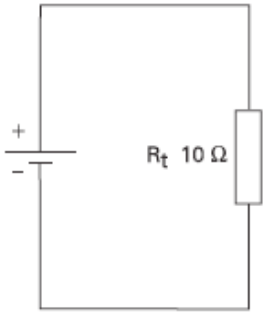
$$R = R_1 + R_2$$

$$R = 10\ \Omega + 10\ \Omega$$

$$R = 20\ \Omega$$

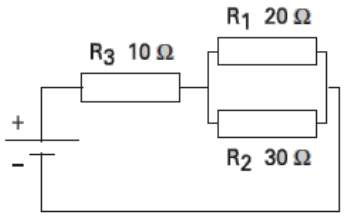
Second, redraw the circuit showing the equivalent values. The result is a simple parallel circuit which uses already learned equations and methods of problem solving.





Review 5

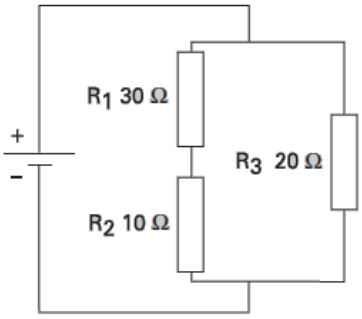
1. Calculate equivalent resistance for R_1 and R_2 and total resistance for the entire circuit.



R_1/R_2 equivalent resistance = _____ Ω

Total resistance = _____ Ω

2. Calculate equivalent resistance for R_1 and R_2 and total resistance for the entire circuit.



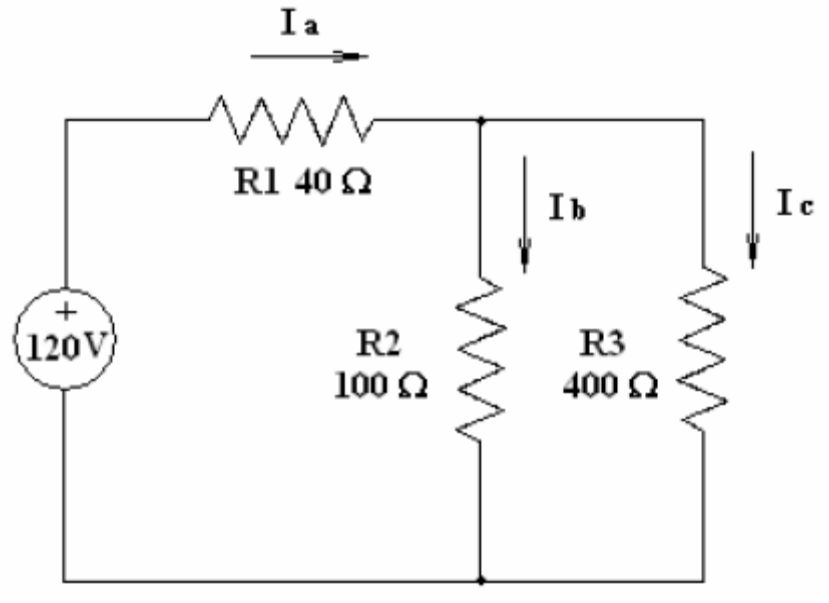
R_1/R_2 equivalent resistance = _____ Ω

Total resistance = _____ Ω

SIEMENS STEP 2000 Self-Study Courses

OVER PLEASE →

Complete the next chart related to the circuit bellow.



Rp	
Rt	
Ia	
Ib	
Ic	
E1	
E2	
E3	
P1	
P2	
P3	
Pt	

Series, Parallel, and Compound circuits questions ☺

Answer the next questions, fill in the blank, or select the right choice.

1) Define a series circuit

_____

_____

2) Define a parallel circuit

_____

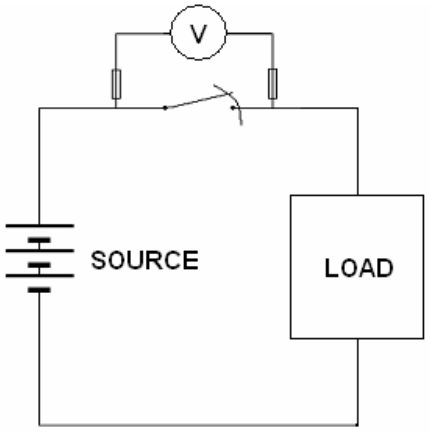
_____

3) In a series circuit the highest resistor produces the highest _____
   a. Current
   b. Conductivity
   c. Voltage drop

4) In a voltage divider, the voltage drop is proportional to _____
   a. The resistor tolerance
   b. Conductance
   c. Resistance

5) In a parallel circuit through the highest resistor circulates the _____ current
   a. Lesser
   b. Highest
   c. Lowest

6) In a current divider, the current of each branch is proportional to _____
   a. The branch resistivity
   b. The branch conductivity
   c. The branch components tolerance



7) What is the potential reading across a switch when opens a circuit :

Source's voltage or 0 volts

8) What is the potential reading across a switch when closes a circuit:

Source's voltage or 0 volts

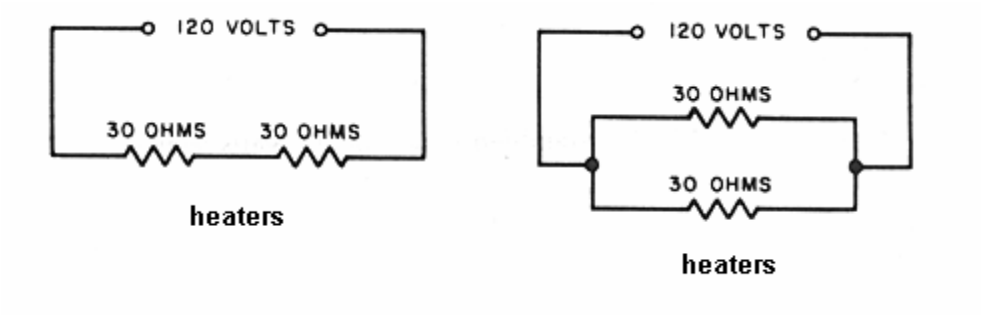
9) In order to avoid changing the condition of a circuit under scrutiny, voltmeters must have very _____ internal resistance

   a. High
   b. Low

10) In order to avoid changing the condition of a circuit under scrutiny, ammeters must have very _____ internal resistance.

   a. High
   b. Low

11) Calculate the amount of calories the appliance in the picture releases in 10 minutes when its heaters are connected in Series or in Parallel (1 W = 0.24 cal per sec)



SERIES CASE	PARALLEL CASE
Conclusion: The heat delivered will be the __ a) Greatest b) Least	Conclusion: The heat delivered will be the__ a) Greatest b) least

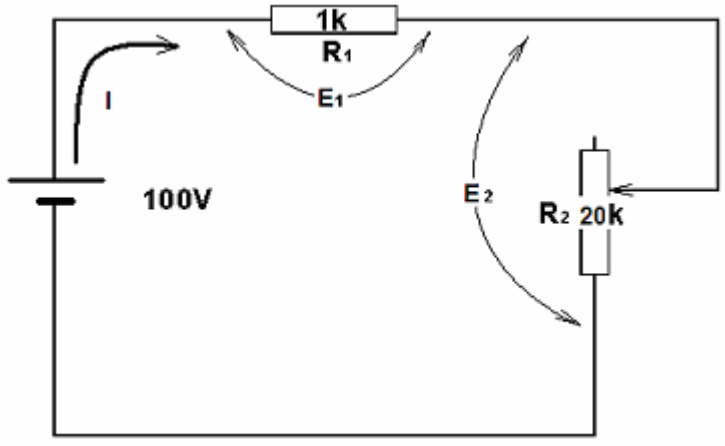
12) In a series circuit the highest component develops the _____power of the series
   a) Greatest
   b) Least

13) In a parallel circuit the branch with the highest current develops the _____ power of the parallel.
   a) Greatest
   b) Least

14) If the total resistance of a circuit decreases, the total power _____

   a) Stays the same
   b) Increases

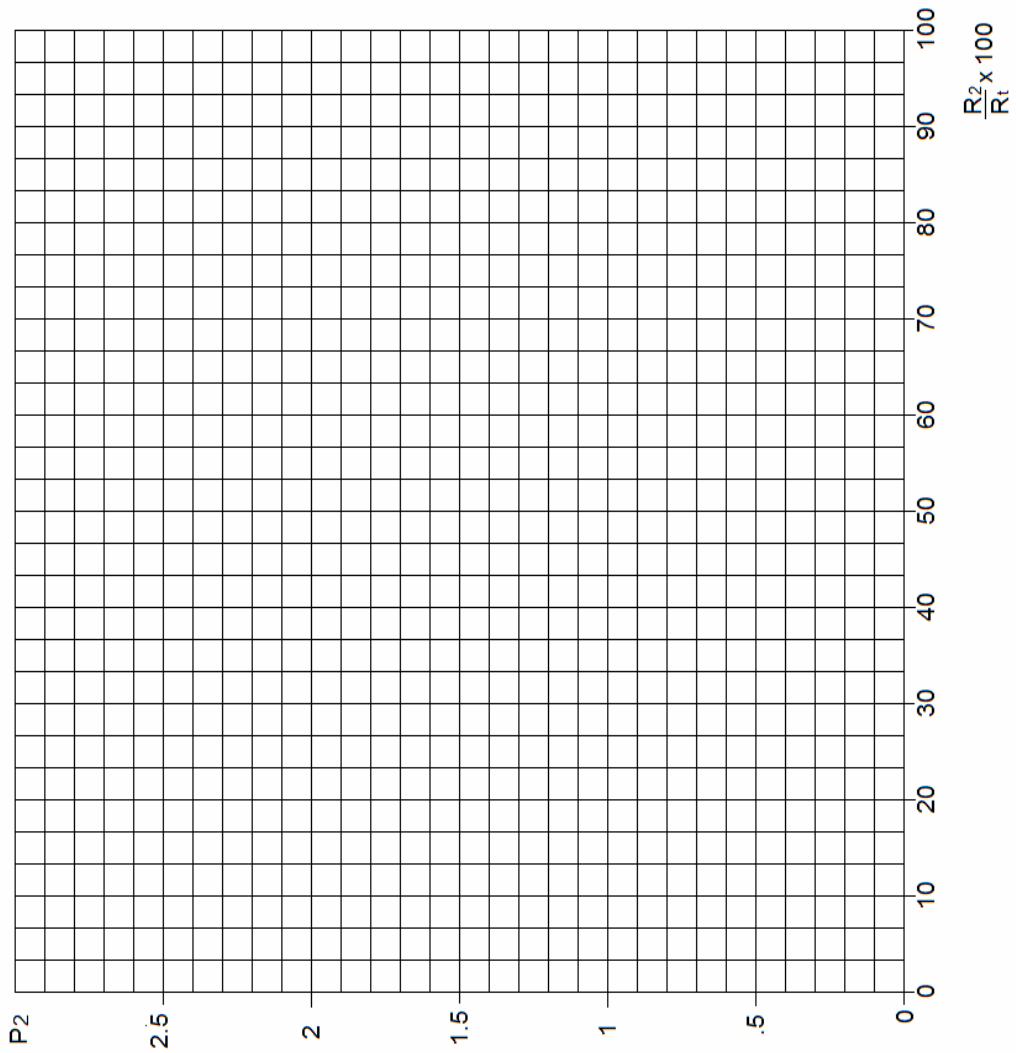
15) Plot $P2 \text{ vs. } \frac{R2}{Rt} \times 100$ for the next circuit



Use **$P_2 = E_2 \times I$ or $P2 = I^2 \times R_2$**

OVER PLEASE→

R_1	R_2	R_t	P_2	$\frac{R_2}{R_t} \times 100$
1 K	0			
1 K	10			
1 K	20			
1 K	30			
1 K	40			
1 K	50			
1 K	60			
1 K	70			
1 K	80			
1 K	90			
1 K	100			
1 K	200			
1 K	300			
1 K	400			
1 K	500			
1 K	600			
1 K	700			
1 K	800			
1 K	900			
1 K	1K			
1 K	2K			
1 K	3K			
1 K	4K			
1 K	5K			
1 K	6K			
1 K	7K			
1 K	8K			
1 K	9K			
1 K	10K			



Fast track analysis

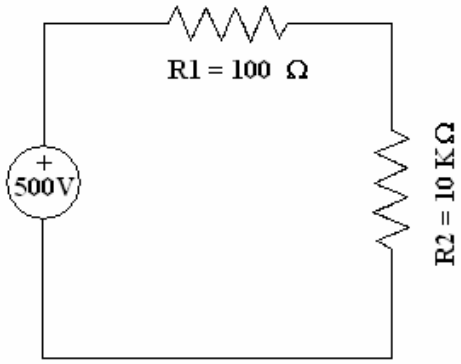
Consider the next facts

If two components are connected in series the voltage drop at each component is proportional to the resistance of each component.

If one of the components of the series is or becomes much larger than the other component – or in a general case, much larger than the combination of the rest of the components members of the series – then the voltage across the large component is much larger than the voltage drop across the other component (or others components).

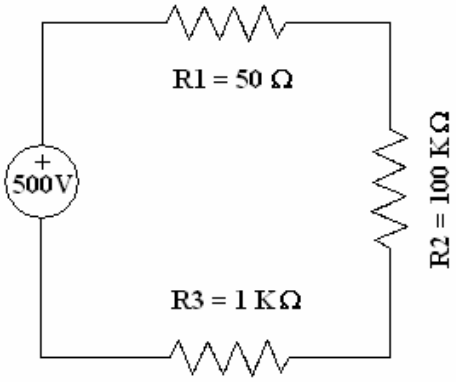
At one point the disproportion is such that the smaller voltage drop becomes negligible. For instance a component 100 times larger than another component, or combination of components, connected in series will produce a voltage drop 100 times larger than the voltage drop across the other component or combined components. For any practical purpose, the voltage drop across the smaller component is negligible in relation to the large component.

To illustrate this point please calculate the voltage drops in the next circuits.



E1 =

E2 =



E1 =

E2 =

E3 =

In both cases R2 belittles anything around, and it is like the source has R2 as its only load. In fact if the other components are replaced by a wire, the total current will not change significantly.

Suppose a series circuit in which one of the components is able to vary from 0 Ω to ∞ Ω; that is from behaving as a conductor to an open circuit in a very brief period of time. How do you think this is going to affect the voltage drop across this variable component and across the other or others components associated to it?

When the variable component is 0 Ω then there is not voltage drop across it and the totality of the voltage is applied to the other or others components. It behaves as a close switch.

When the variable component is very large (very large resistance ~ ∞ Ω) the voltage drop across it will be proportionally large, up to the point to make negligible what is left. It can be very close to zero… so it behaves as an open switch. Anything else in the series will still be connected, but there will be not (or virtually not) voltage applied to it; so although connected it will be OFF

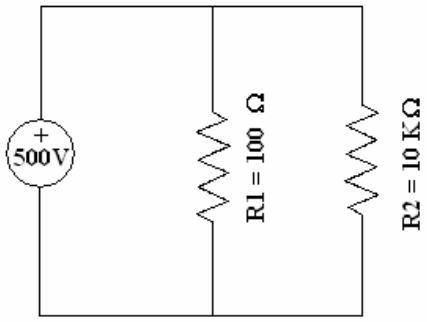
Solid state switches use this mechanism to control the flow of current through loads.

If two components are connected in parallel the current at each component is inversely proportional to the resistance of each component.

If one of the components of the parallel is or becomes much smaller than the other component – or for a general case, much smaller than the combination of the rest components members of the parallel – Then the current through the small component is much larger than the current through the other component (or others components).

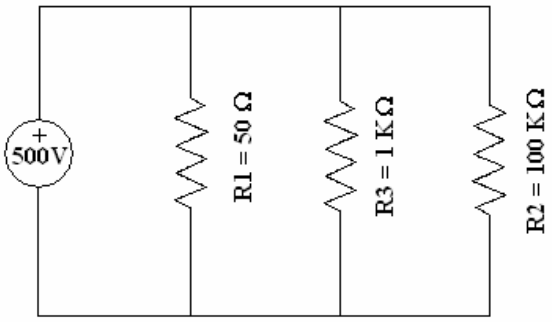
At one point the disproportion is such that the smaller current/s become/s negligible. For instance a component 100 times smaller than other component, or combination of components, connected in parallel will drain a current 100 times larger than the current drained by the other component or combined components. For any practical purpose, the current drained the larger component is negligible in respect of the other small component.

To illustrate this point please calculate the branch currents in the next circuits (compare the branch currents with the total current drained from the source)



I_1 =

I_2 =



I_1 =

I_2 =

I_3 =

There are control applications related to this fact, but also it is a useful model to keep in mind when analyzing circuits. The extreme low resistance path across a parallel receives the name of a "SHUNT". Also, when this case happens by error receive the name of "short-circuit" – sounds familiar? ☺

In the extreme case of a branch that drops its resistivity close to zero, all – or virtually all – of the current will flow through it.
Because the source DO have an internal resistance (very low but existent) the internal voltage drop at the source increases dramatically and the external difference of potential falls close to zero. Since no difference of potential is present across the rest of the components connected in parallel, although they remain connected, they are said to be in OFF state.

In real world applications Series-Parallel configurations are usually an appropriate model for analysis.

For example, a control device is usually connected in series with one or more loads that are connected in parallel (Fig A).

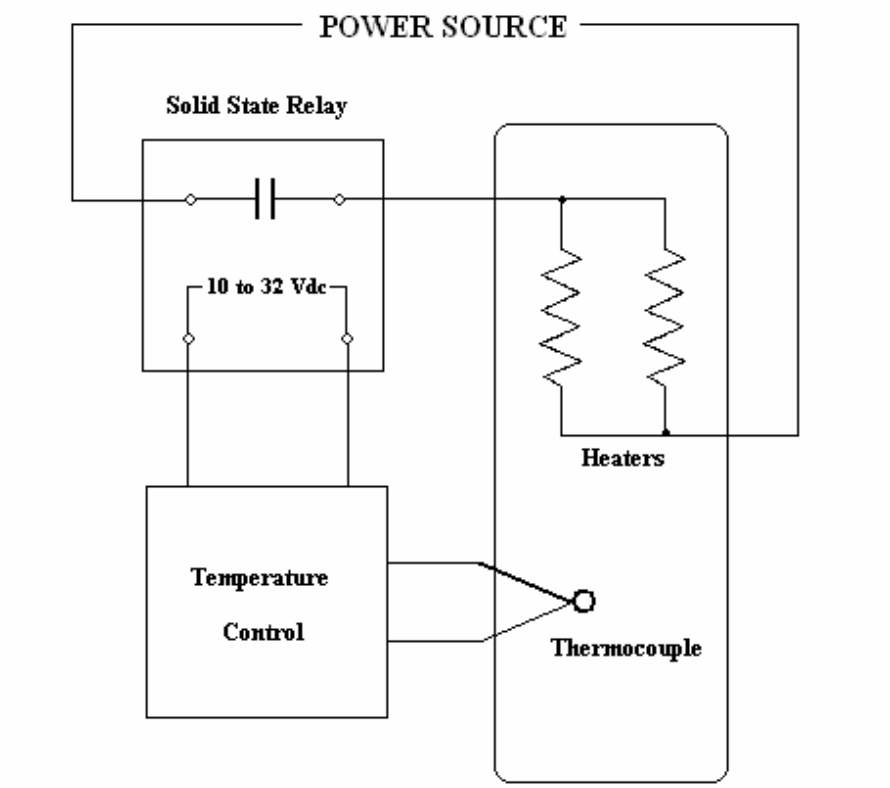


Fig A

The mechanical contact display into the SS relay, is only the representation of the function. In fact, that contact is a small block made of semiconductor materials which change their resistance level depending on the presence or not presence of voltage in the input terminals - 10 to 32 Vdc

Another example: A source that feeds a group of loads can be represented as a pure voltage source – an EMF source – connected in **SERIES** with the EMF source there is a resistor that represents all the imperfections of the source that produces losses, and all the loads are connected in parallel (Fig B)

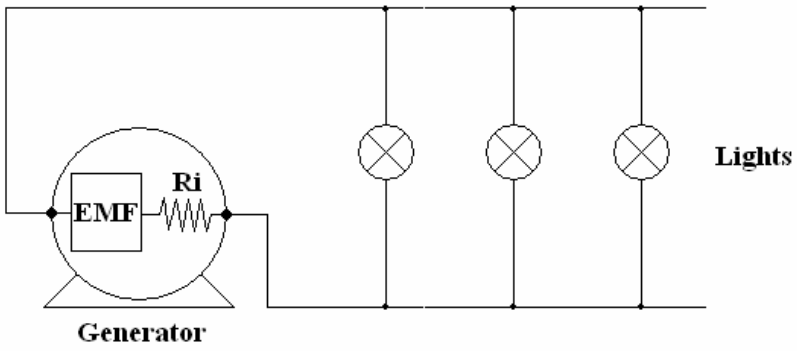


Fig B

WEEK 6

Notes

Notes

Notes

Notes

Coils & Capacitors

Introduction:

This lab is a practical demonstration of the effects of electric fields manipulation (related to capacitors in Part I), and magnetic fields manipulation (related to inductors in Part II).

The following circuits demonstrate that it is possible to store and manipulate energy using coils and capacitors.

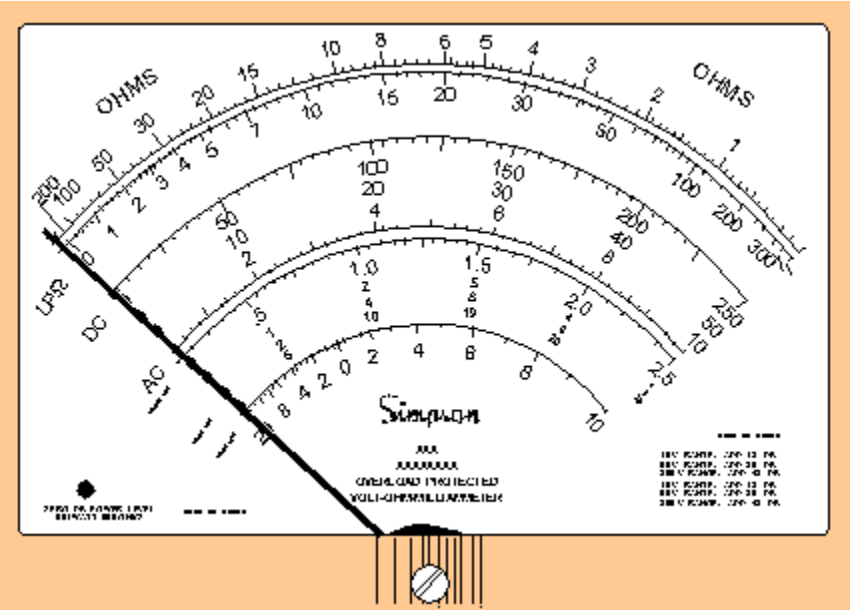
First a brief introduction to analog multimeters

Analog multimeters were the work-horse for electricians, technicians and engineers for several decades until the development of cost effective solid state instruments. Although analog multimeters are not as common in the field as they used to be, still today this venerable technology is present in many work benches and work stations.

The operation of these instruments is not far different than the digital units we have been using along these labs. What really differs is the way the information is collected and is retrieve.

Digitals sample and process the input and transform it as information that is presented as a number in the display. Analogs, such as the old multimeter you are about to use, just react in immediate and direct proportion to the variable measured. There is not sampling, no processing; some energy from the circuit under scrutiny is drain in order to move the pointer in a graded scale that sometimes demand some training to read correctly.

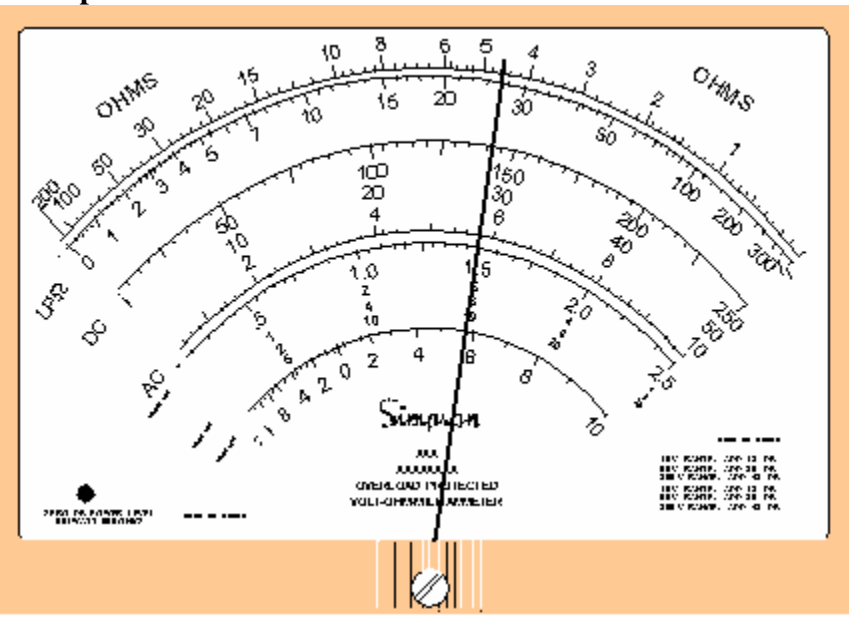
The display of the analog multimeter that will be used in this lab looks like the next picture

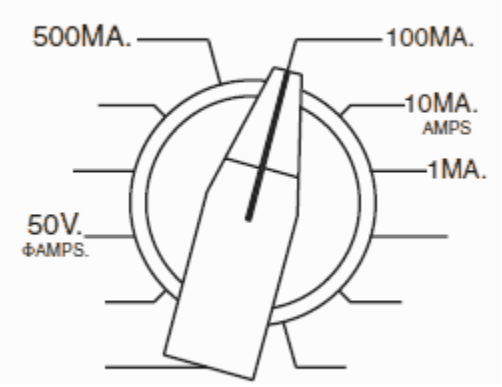


Three legends stand out:

1. OHMS
2. DC
3. AC

Although they have different scaled traces to read, the DC and the AC scales share the same numerical values arranged in three lists. From top to bottom:
0 to 250
0 to 50
0 to 10
These scales are going to be used either for voltage or current measurements. If DC variables are read, then the top DC trace shall be used as reference; if AC variables are being measured, then the bottom trace. The value of the point where the pointer points depend on the scale selected in the rotary switch.
Example:





For the 100, 10, and 1 mA scales the set of values to be considered is the last one: 0 to 10.
In the case of the picture, 10 shall be read as 100, 1 as 10, 2 as 20, and so on.
The sub-marks are going to be 0.2 of the minimum value of a full mark.
As the picture shows, the pointer is at slightly more than three subdivisions from 5 and slightly less than two subdivisions from 6. Then the reading is > 5.6 then the reading is 56mA (the actual reading shall be multiplied by 10)
If the rotary switch were in the 1mA the reading then should be 0.56mA (the actual reading should be divided by 10).
If the rotary switch were in the 10mA position then the reading should be 5.6mA
If the rotary switch were in the 500mA position, then the 0 to 50 set of values should be considered. In such case the reading should be >28mA.
Same criterion applies to voltage measurements.
Resistance measurements have extra requirements since the instrument needs to be adjusted previous to be used as ohm-meter. User manuals for any analog multimeter are available in the INTERNET.

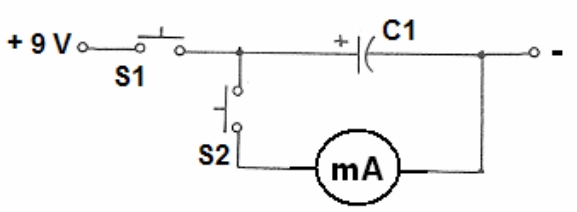
Part I

Storing Energy Using Capacitors
Association of Capacitors

Experiment 1

Follow the next procedure. Read the whole instruction before executing it.

Using a protoboard connect the components as shown in the schematic



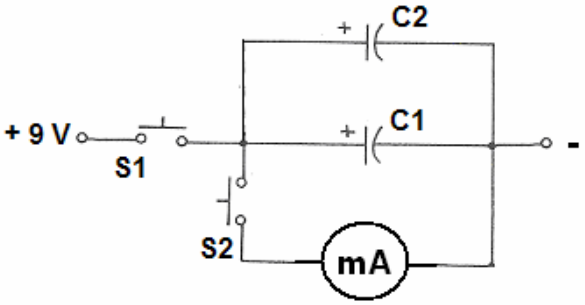
C1 = 100µF

WARNING!!! Do not press simultaneously S1 and S2 because that will cause a direct short through the instrument.

1 Press S1
2 Release S1 - Now C1 is charged [*!*]
3 Press S2 – it will discharge C1 – **Try to observe the peak value of the current and write it down.** Release S2 only after the pointer has stopped completely.
4 Connect the components as shown in the schematic

Peak Current

C1 = C2 = 100µF



WARNING!!! Do not press simultaneously S1 and S2 because that will cause a direct short through the instrument.

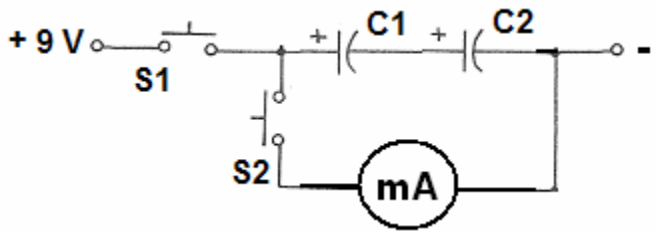
5 Press S1
6 Release S1– Now both capacitors are charged.
7 Press S2 – what will discharge C1 and C2 – **Try to observe the peak value of the current and write it down.** Release S2 only after the needle has stopped completely.
8 Release S2.

Peak Current

The highest peak has occurred when (choose the correct answer):

a) C1 was alone
b) C1 and C2 were connected in parallel

9 Connect C1 and C2 in series as shown in the next schematic.



WARNING!!! Do not press simultaneously S1 and S2 because that will cause a direct short through the instrument.

10 Press S1
11 Release S1– now both capacitors are charged.
12 Press S2 – what will discharge C1 and C2 – **Try to observe the peak value of the current and write down** and release S2 only after the pointer has stopped completely.
13 Release S2.

Peak Current

14 The peak current was _____ (select the best answer)
a) The lowest of all three experiments
b) The highest of all three experiments
c) Lower than the first case (only one capacitor)
d) Higher than the first case (only one capacitor)

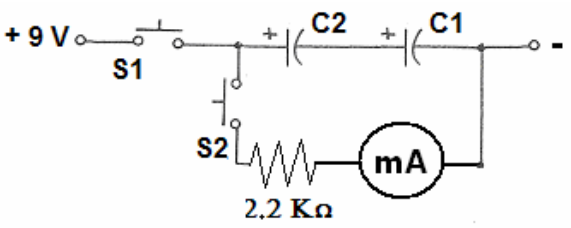
Experiment 2

^^^

CASE 3: Connect the components as shown in the schematic.

1) Press S1
2) Release S1 - Now C1 and C2 are charged [!]
3) Press S2 and do not release S2 until the pointer stop.– <u>Measure how long it takes to discharge C1 and C2</u>

Discharge Time
sec



The time measured is approximately $5 \times \tau$.

Because… $\tau_c = RC$,and $5\tau_c = 5RC$ (Time measured)

Then $\frac{\text{Time measured}}{5R} = C$

Based on this formula, it is possible to calculate the total capacitance of each circuit by using the known value of the resistor and the time measured in each case. Therefore it is verified empirically the effects of connecting capacitors in series and in parallel

Step	Time measured	Capacitance calculated
1	sec	µF
2	sec	µF
3	sec	µF

Please compare the capacitance calculated from the data of your experiment with the theoretical value of capacitance from the generic formulas, using the capacitances printed in the capacitors:

$$C_{parallel} = C1 + C2$$

$$C_{series} = \frac{1}{\frac{1}{C1} + \frac{1}{C2}}$$

CASE	Calculated from	
	Formula	Data
1*	µF	µF
2	µF	µF
3	µF	µF

* In CASE 1 there is no formula to use because there is only one capacitor, so the value to write under "Formula" is the value printed in the label of the capacitor

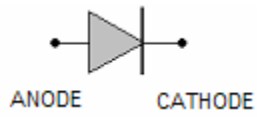
PART II

Before starting let's talk a few words about two components that will be used along this second part: DIODES and LEDs.

DIODES are semiconductor, components made of silicon, germanium, and other substances treated in a special way to make them conductive only under specific conditions, such as polarity and voltage level.

There are different types of diodes, "diodes rectifiers", "Zener diodes", "Schottky diodes", "Light Emitter Diodes (LEDs)" …

Their symbols are similar to one another, and all of them are based on the next basic drawing where the names of its parts are indicated.



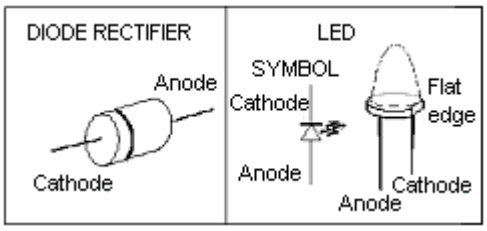
The triangle-end is called the "anode" while the line-end is the "cathode".

In disregard of the type of diode, when the potential in the anode is higher than the potential in the cathode, and the difference of potential reaches a critical point, the diode becomes conductive like a close switch – in technical terms it is said: It is in "FORWARD BIAS".

When polarity is reverse (REVERSE BIAS – the potential in the anode is lower than the potential in the cathode), the diode behaves as an open switch (zener diodes are exceptions).

In the case of LEDs, the FORWARD BIAS condition makes them glow, and the brightness will depend on the amount of current flowing through. LEDs come in different colors such as red, green, yellow, blue, and white; and there are multicolor units that can glow in three different colors. New ground breaking developments are replacing traditional lighting devices with high efficiency high luminance LEDs.

From a practical stand point, anodes and cathodes are recognizable by characteristic features in the components as shown in the next picture



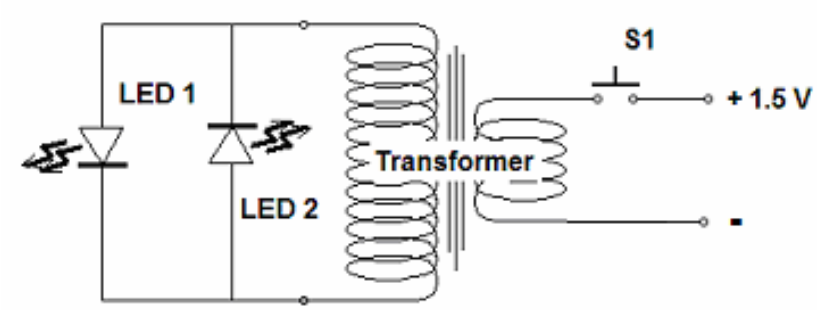
Transferring Energy Using Coils

Experiment 1

A transformer is basically a set of coils wound around a common core. This arrangement allows the transference of energy from one coil to the other by means of a fluctuating magnetic field

1 Identify the coil with lower resistance and connect it to the power supply through S1 as shown in the figure bellow. Then, across the coil with higher resistance connect the LEDs as indicated (anti-parallel connection – for any given polarity, only one LED will light up).

2 Set the power supply at 1.5V



NOTE → Both coils are electrically isolated from one another; their link is only magnetic. [*!*]

3 Press S1 for one second and then release it

One LED flashes when S1 is pressed and the other when S1 is released.

LED 1 and LED 2 flash at different moments, and the only way to light them up is by repeatedly toggling S1. Keeping S1 pressed does not keep one LED ON.

The reason for such phenomenon is that the transference of energy only occurs when the magnetic field, created by the coil connected to the power supply, varies; whether it is expanding or collapsing.

Since a current must flow through a LED, in order to bright it up, a voltage level must be reached.

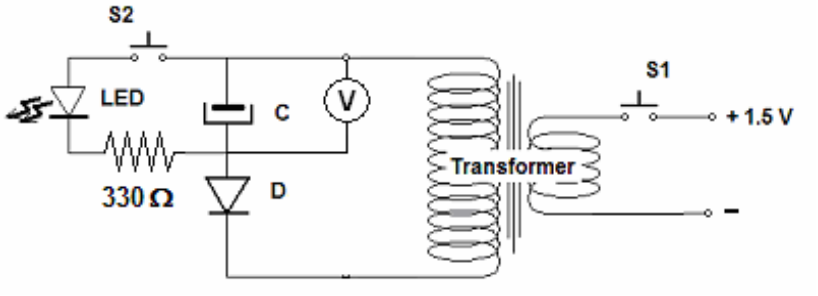
Mmmmm across the coil that it is not connected to the power supply a voltage must be present and a current is flowing through… so….

what the toggling is doing is… transferring POWER doing work in a period of time… mmmmm That's ENERGY [***!!!***]

The toggling causes the magnetic field to expand and collapse successively in one coil inducing a voltage in the other coil and propelling a current through the LEDs!!!

Experiment 2

Please build the next circuit where D is a diode (1N4148 or similar) and C is 1000 µF.



Please follow the next instructions.

1 Toggle S1;

2 Press S2 and keep it pressed for a couple of seconds; have you seen the LED flash?

YES NO

3 Toggle S1 two times;

4 Press S2 and keep it pressed for a couple of seconds; have you seen the LED flash?

YES NO

5 Toggle S1 four times;

6 Press S2 and keep it pressed for a couple of seconds; have you seen the LED flash?

YES NO

7 Toggle S1 eight times;

8 Press S2 and keep it pressed for a couple of seconds; have you seen the LED flash?

YES NO

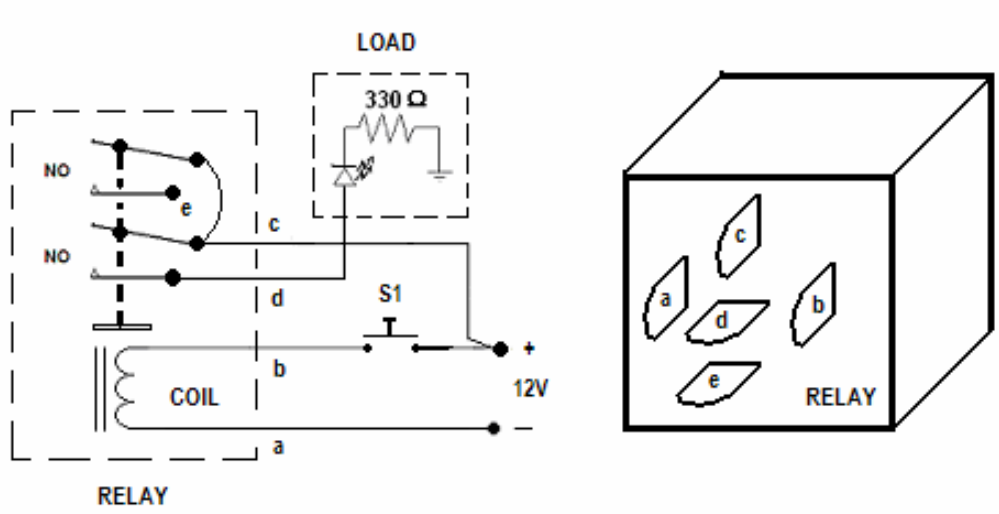
Does the LED light up longer periods of time along the experiment? YES NO

Does the reading of the voltmeter increase? YES NO

Experiment 3

Capacitors used for temporization purposes and coils used to create movement

Build the next circuit



The ground symbol in this diagram means a connection back to the negative

When S1 is toggled the relay's contacts change state (from open to close), and the LED turns ON and OFF as S1 is toggled – THE COIL IS CONVERTING ELECTRICAL ENERGY INTO MECHANICAL ENERGY – It consumes electrical power to deliver mechanical power…

Does it sounds a ring?... … It's doing what electric motors do, not only transfer energy, but also convert it !!! AWESOME!!! …

There is no charge for awesomeness…

Now introduce in the circuit C1 and C2 as shown in the schematic.

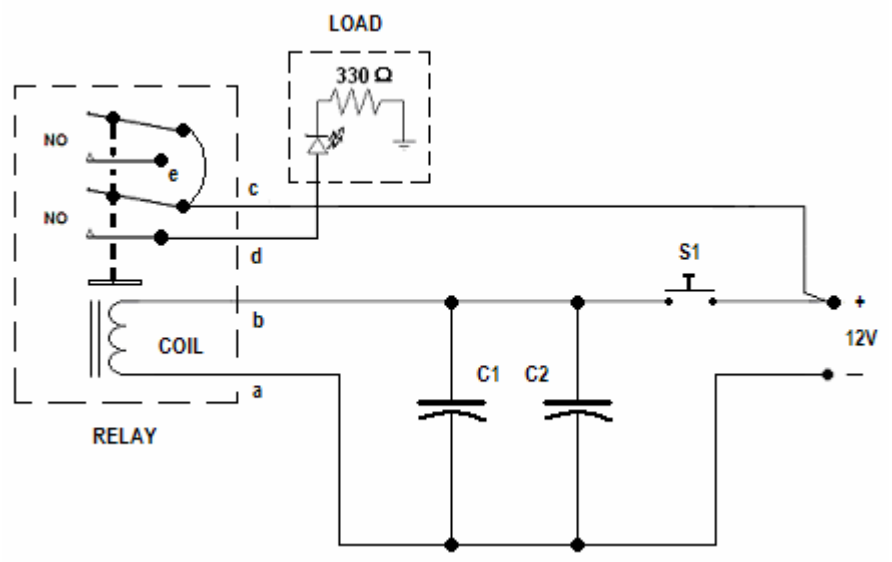
C1=C2=1000 µF

Why are the capacitors connected in parallel? __

a. To decrease capacitance
b. To increase capacitance

What is the capacitance of these capacitors connected in parallel?

µF



Now toggle S1

What had it happened? _____

a. The LED stayed OFF
b. The LED blinked
c. The LED was lighted for a longer period of time

Why?

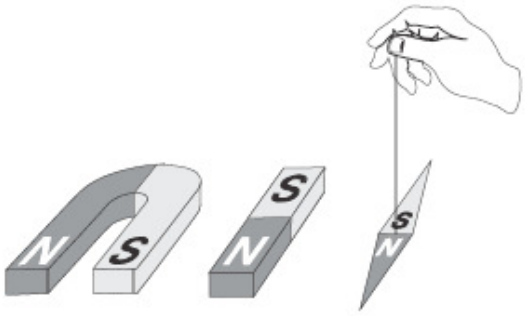
_____

Magnetism

The principles of magnetism are an intregal part of electricity. Electromagnets are used in some direct current circuits. Alternating current cannot be understood without first understanding magnetism.

Types of magnets

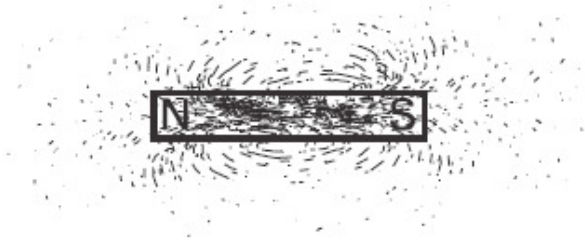
The three most common forms of magnets are the horseshoe, bar and compass needle.



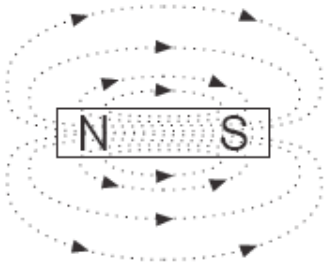
All magnets have two characteristics. They attract and hold iron. If free to move, like the compass needle, the magnet will assume roughly a north-south position.

Magnetic lines of flux

Every magnet has two poles, one north pole and one south pole. This is the point at which maximum attraction occurs. Invisible magnetic lines of flux leave the north pole and enter the south pole. While the lines of flux are invisible, the effects of magnetic fields can be made visible. When a sheet of paper is placed on a magnet and iron filings loosely scattered over it, the filings will arrange themselves along the invisible lines of flux.



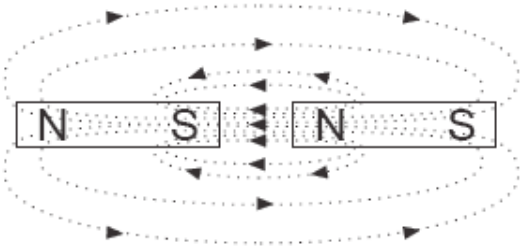
By drawing lines the way the iron filings have arranged themselves, the following picture is obtained.

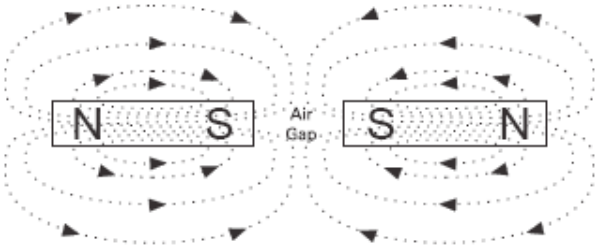


Broken lines indicate the paths of magnetic flux lines. The field lines exist outside and inside the magnet. The magnetic lines of flux always form closed loops. Magnetic lines of flux leave the north pole and enter the south pole, returning to the north pole through the magnet.

Interaction between two magnets

When two magnets are brought together, the magnetic flux field around the magnet causes some form of interaction. Two unlike poles brought together cause the magnets to attract each other. Two like poles brought together cause the magnets to repel each other.

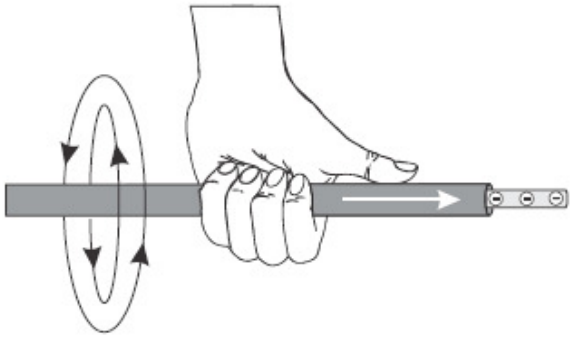




Electromagnetism

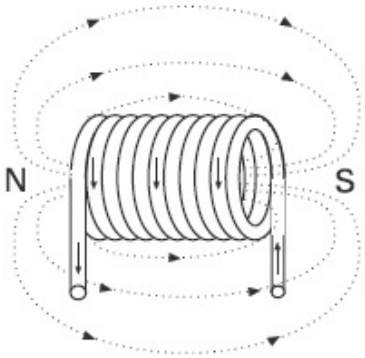
Left-hand rule for conductors

An electromagnetic field is a magnetic field generated by current flow in a conductor. Whenever current flows a magnetic field exists around the conductor. Every electric current generates a magnetic field. A definite relationship exists between the direction of current flow and the direction of the magnetic field. The left-hand rule for conductors demonstrates this relationship. If a current-carrying conductor is grasped with the left hand with the thumb pointing in the direction of electron flow, the fingers will point in the direction of the magnetic lines of flux.



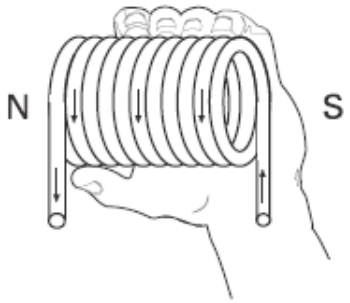
Current-carrying coil

A coil of wire carrying a current acts like a magnet. Individual loops of wire act as small magnets. The individual fields add together to form one magnet. The strength of the field can be increased by adding more turns to the coil. The strength can also be increased by increasing the current.



Left-hand rule for coils

A left-hand rule exists for coils to determine the direction of the magnetic field. The fingers of the left hand are wrapped around the coil in the direction of electron flow. The thumb points to the north pole of the coil.



Electromagnets

An electromagnet is composed of a coil of wire wound around a core. The core is usually a soft iron which conducts magnetic lines of force with relative ease. When current is passed through the coil, the core becomes magnetized. The ability to control the strength and direction of the magnetic force makes electromagnets useful. As with permanent magnets, opposite poles attract. An electromagnet can be made to control the strength of its field which controls the strength of the magnetic poles.

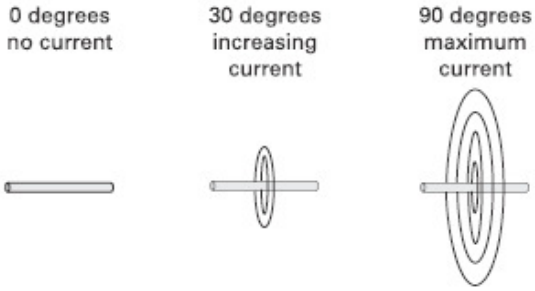
A large variety of electrical devices such as motors, circuit breakers, contactors, relays and motor starters use electro-magnetic principles.

Inductance

The circuits studied to this point have been resistive. Resistance and voltage are not the only circuit properties that effect current flow, however. Inductance is the property of an electric circuit that opposes any change in electric current. Resistance opposes current flow, inductance opposes change in current flow. Inductance is designated by the letter "L". The unit of measurement for inductance is the henry (h).

Current flow and field strength

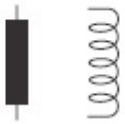
Current flow produces a magnetic field in a conductor. The amount of current determines the strength of the magnetic field. As current flow increases, field strength increases, and as current flow decrease, field strength decreases.



Any change in current causes a corresponding change in the magnetic field surrounding the conductor. Current is constant in DC, except when the circuit is turned on and off, or when there is a load change. Current is constantly changing in AC, so inductance is a continual factor. A change in the magnetic field surrounding the conductor induces a voltage in the conductor. This self-induced voltage opposes the change in current. This is known as counter emf. This opposition causes a delay in the time it takes current to attain its new steady value. If current increases, inductance tries to hold it down. If current decreases, inductance tries to hold it up. Inductance is somewhat like mechanical inertia, which must be overcome to get a mechanical object moving, or to stop a mechanical object from moving. A vehicle, for example, takes a few moments to accelerate to a desired speed, or decelerate to a stop.

Inductors

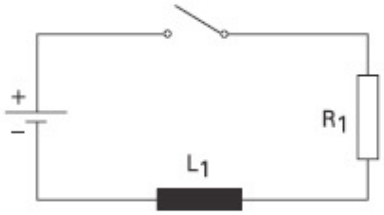
Inductance is usually indicated symbolically on an electrical drawing by one of two ways. A curled line or a filled rectangle can be used.



Inductors are coils of wire. They may be wrapped around a core. The inductance of a coil is determined by the number of turns in the coil, the spacing between the turns, the coil diameter, the core material, the number of layers of windings, the type of winding, and the shape of the coil. Examples of inductors are transformers, chokes, and motors.

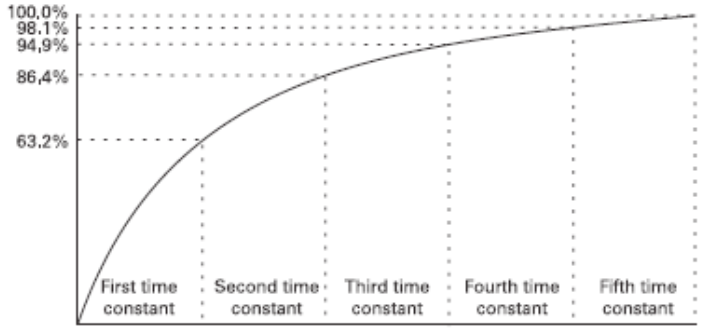
Simple inductive circuit

In a resistive circuit, current change is considered instantaneous. If an inductor is used, the current does not change as quickly. In the following circuit, initially the switch is open and there is no current flow. When the switch is closed, current will rise rapidly at first, then more slowly as the maximum value is approached. For the purpose of explanation, a DC circuit is used.

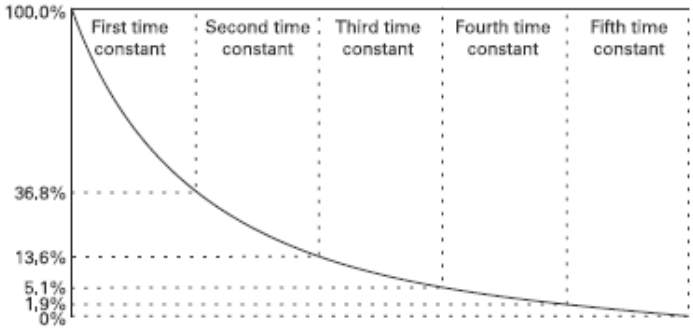


Inductive time constant

The time required for the current to rise to its maximum value is determined by the ratio of inductance, in henrys, to resistance, in ohms. This ratio is called the time constant of the inductive circuit. A time constant is the time, in seconds, required for the circuit current to rise to 63.2% of its maximum value. When the switch is closed in the previous circuit, current will begin to flow. During the first time constant current rises to 63.2% of its maximum value. During the second time constant, current rises to 63.2% of the remaining 36.8%, or a total of 86.4%. It takes about five time constants for current to reach its maximum value.



Similarly, when the switch is opened, it will take five time constants for current to reach zero. It can be seen that inductance is an important factor in AC circuits. If the frequency is 60 hertz, current will rise and fall from its peak value to zero 120 times a second.



Calculating the time constant of an inductive circuit

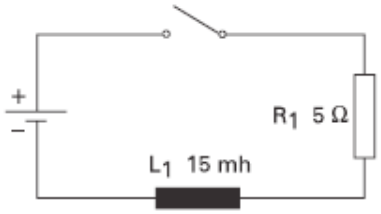
The time constant is designated by the symbol "τ". To determine the time constant of an inductive circuit use one of the following formulas:

$$\tau(\text{in seconds}) = \frac{L(\text{henrys})}{R(\text{ohms})}$$

$$\tau(\text{in milliseconds}) = \frac{L(\text{millihenrys})}{R(\text{ohms})}$$

$$\tau(\text{in microseconds}) = \frac{L(\text{microhenrys})}{R(\text{ohms})}$$

In the following illustration, L_1 is equal to 15 millihenrys and R_1 is equal to 5 Ω. When the switch is closed, it will take 3 milliseconds for current to rise from zero to 63.2% of its maximum value.



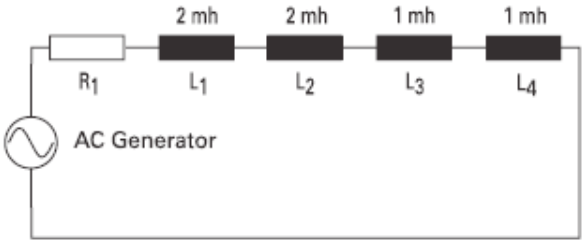
$$\tau = \frac{15\ mh}{5\ \Omega}$$

$$\tau = 3\ milliseconds$$

Formula for series inductors

The same rules for calculating total resistance can be applied. In the following circuit, an AC generator is used to supply electrical power to four inductors. There will always be some amount of resistance and inductance in any circuit. The electrical wire used in the circuit and the inductors both have some resistance and inductance. Total inductance is calculated using the following formula:

$$L_t = L_1 + L_2 + L_3$$



$$L_t = L_1 + L_2 + L_3 + L_4$$

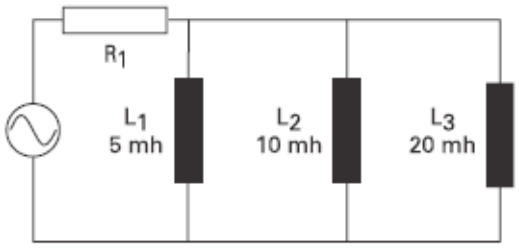
$$L_t = 2\ mh + 2\ mh + 1\ mh + 1\ mh$$

$$L_t = 6\ mh$$

Formula for parallel inductors

In the following circuit, an AC generator is used to supply electrical power to three inductors. Total inductance is calculated using the following formula:

$$\frac{1}{L_t} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$$



$$\frac{1}{L_t} = \frac{1}{5} + \frac{1}{10} + \frac{1}{20}$$

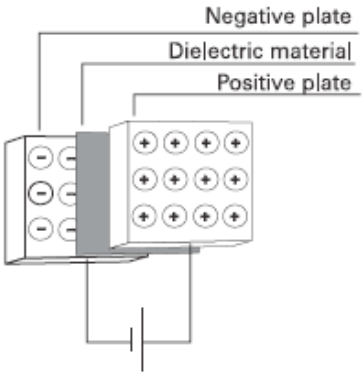
$$\frac{1}{L_t} = \frac{7}{20}$$

$$Lt = 2.86\ mh$$

Capacitance

Capacitance and capacitors

Capacitance is a measure of a circuit's ability to store an electrical charge. A device manufactured to have a specific amount of capacitance is called a capacitor. A capacitor is made up of a pair of conductive plates separated by a thin layer of insulating material. Another name for the insulating material is dielectric material. When a voltage is applied to the plates, electrons are forced onto one plate. That plate has an excess of electrons while the other plate has a deficiency of electrons. The plate with an excess of electrons is negatively charged. The plate with a deficiency of electrons is positively charged.



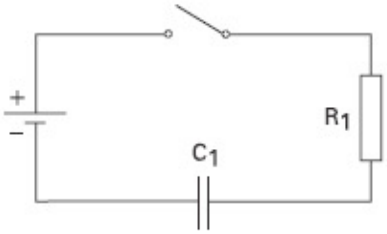
Direct current cannot flow through the dielectric material because it is an insulator. Capacitors have a capacity to hold a specific quantity of electrons. The capacitance of a capacitor depends on the area of the plates, the distance between the plates, and the material of the dielectric. The unit of measurement for capacitance is farads, abbreviated "F". Capacitors usually are rated in µF (microfarads), or pF (picofarads).

Capacitor circuit symbols

Capacitance is usually indicated symbolically on an electrical drawing by a combination of a straight line with a curved line, or two straight lines.

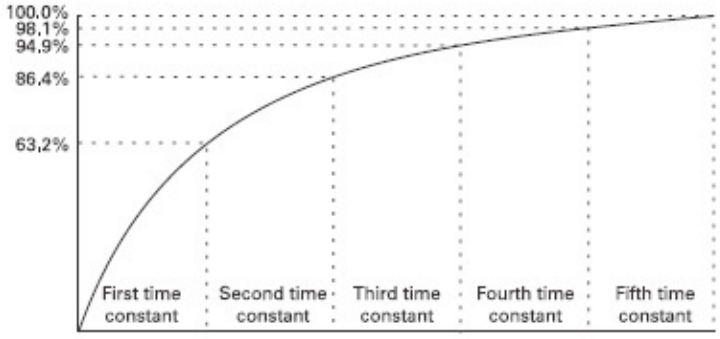
Simple capacitive circuit

In a resistive circuit, voltage change is considered instantaneous. If a capacitor is used, the voltage across the capacitor does not change as quickly. In the following circuit, initially the switch is open and no voltage is applied to the capacitor. When the switch is closed, voltage across the capacitor will rise rapidly at first, then more slowly as the maximum value is approached. For the purpose of explanation, a DC circuit is used.

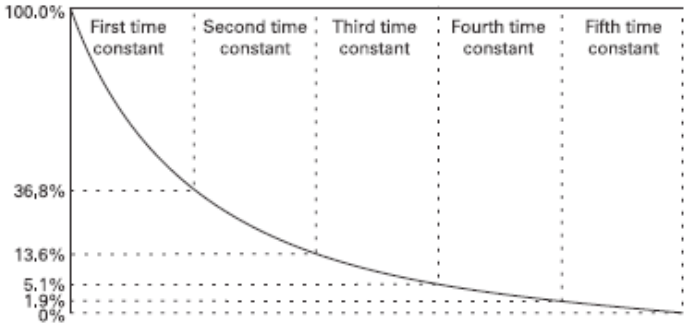


Capacitive time constant

The time required for voltage to rise to its maximum value in a circuit containing capacitance is determined by the product of capacitance, in farads, times resistance, in ohms. This is the time it takes a capacitor to become fully charged. This product is the time constant of a capacitive circuit. The time constant gives the time in seconds required for voltage across the capacitor to reach 63.2% of its maximum value. When the switch is closed in the previous circuit, voltage will be applied. During the first time constant, voltage will rise to 63.2% of its maximum value. During the second time constant, voltage will rise to 63.2% of the remaining 36.8%, or a total of 86.4%. It takes about five time constants for voltage across the capacitor to reach its maximum value.



Similarly, during this same time, it will take five time constants for current through the resistor to reach zero.



Calculating the time constant of a capacitive circuit

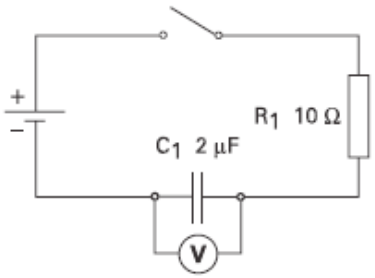
To determine the time constant of a capacitive circuit, use one of the following formulas:

$\tau(\text{in seconds}) = R(\text{megohms}) \times C(\text{microfarads})$

$\tau(\text{in microseconds}) = R(\text{megohms}) \times C(\text{picofarads})$

$\tau(\text{in microseconds}) = R(\text{ohms}) \times C(\text{microfarads})$

In the following illustration, C_1 is equal to 2 µF, and R_1 is equal to 10 Ω. When the switch is closed, it will take 20 microseconds for voltage across the capacitor to rise from zero to 63.2% of its maximum value. There are five time constants, so it will take 100 microseconds for this voltage to rise to its maximum value.



$\tau = RC$

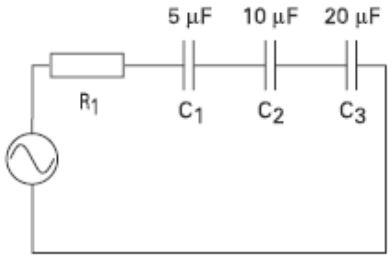
$\tau = 2\ \mu F \times 10\ \Omega$

$\tau = 20\ \text{microseconds}$

Formula for series capacitors

Connecting capacitors in series decreases total capacitance. The effect is like increasing the space between the plates. The rules for parallel resistance apply to series capacitance. In the following circuit, an AC generator supplies electrical power to three capacitors. Total capacitance is calculated using the following formula:

$$\frac{1}{C_t} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$



$$\frac{1}{C_t} = \frac{1}{5} + \frac{1}{10} + \frac{1}{20}$$

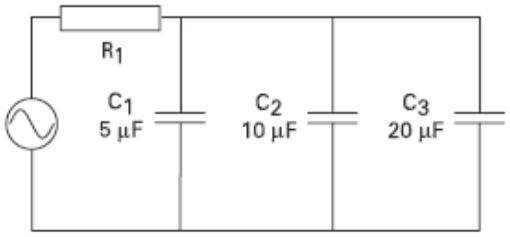
$$\frac{1}{C_t} = \frac{7}{20}$$

$$C_t = 2.86\ \mu F$$

Formula for parallel capacitors

In the following circuit, an AC generator is used to supply electrical power to three capacitors. Total capacitance is calculated using the following formula:

$$C_t = C_1 + C_2 + C_3$$



$$C_t = 5\ \mu F + 10\ \mu F + 20\ \mu F$$

$$C_t = 35\ \mu F$$

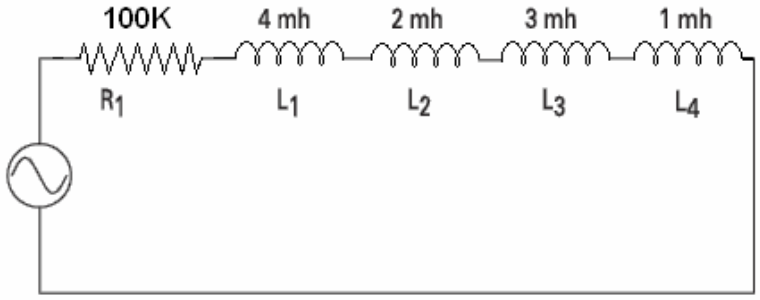
Review 6

1. The rate at which work is done is called _____ .
2. The basic formula for power is _____ .
3. In a circuit with a 12 volt supply and 4 Ω resistance the power consumed is _____ watts.
4. The two characteristics of all magnets are; they attract and hold _____ , and if free to move will assume roughly a _____ position.
5. Lines of flux always leave the _____ pole and enter the _____ pole.
6. The left-hand rule for conductors states that when the _____ hand is placed on a current-carrying conductor with the _____ pointing in the direction of electron flow, the fingers will point in the direction of _____ .

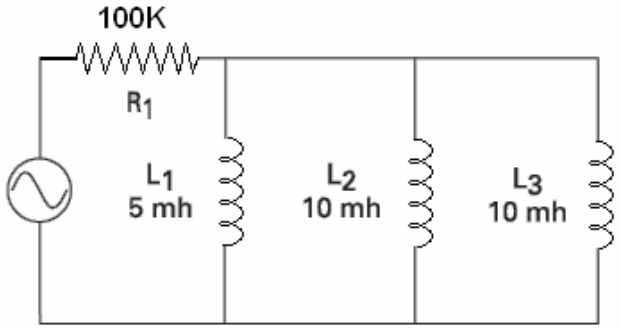
STEP 2000
Self-Study Courses
SIEMENS

Review 7

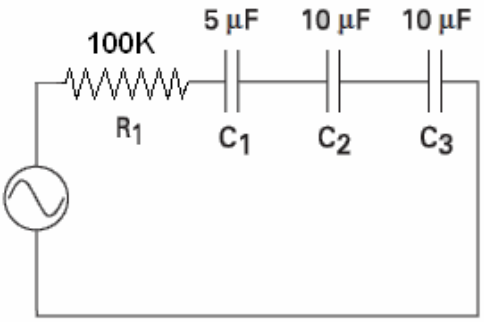
1. The total inductance for this circuit is _____ .



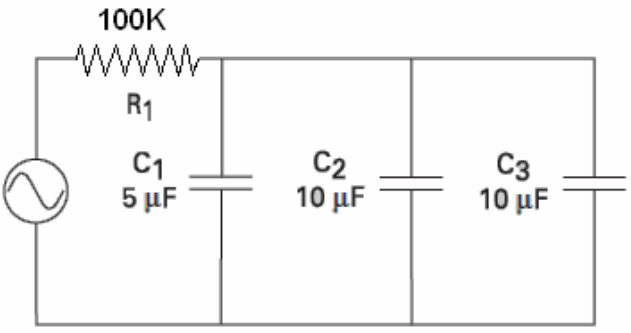
2. The total inductance for this circuit is _____ .



3. The total capacitance for this circuit is _____ .



4. The total capacitance for this circuit is _____ .



Problems – RC and RL Time Constants

SHOW YOUR WORK

1 From Review 7 problem 1 – Calculate τ_L of the circuit

2 From Review 7 problem 2 – Calculate τ_L of the circuit

3 From Review 7 problem 3 – Calculate τ_C of the circuit

4 From Review 7 problem 4 – Calculate τ_C of the circuit

WEEK 7

Midterm

Notes

Notes

Notes

Notes

WEEK 8

Notes

Notes

Notes

Notes

OSCILLOSCOPES

…Your best friend in electronics.

.

☑ The instructions for this labs are based on the basic set of instructions to use a Tektronix TDS 2002 – The full user manual can be download from

http://www2.tek.com/cmswpt/madetails.lotr?ct=MA&cs=mur&ci=15222&lc=EN

PART I

Turn the Oscilloscope ON

Insert the Oscilloscope's probe in Channel ONE (CH 1). Probes have a switch to set a level of attenuation. Set the probe in X1 (no attenuation).

Press the [CH 1 MENU] button. At the right of the screen CH 1 MENU will appear.

The options displayed are	1. Coupling 2. BW (Band Width) Limit 3. Volts/Div (Volts per Divisions) 4. Probe 5. Invert

:

There are five push buttons with grooves connecting them with each item in the menu, by pressing them different options can be selected for each item.

i.e.: Pressing the [Coupling] button the possibilities are DC, AC, and Ground
Try pressing the Coupling button and change the coupling mode.

Select:

- **Coupling = Ground**
- **Volt/Div = Coarse**
- **Probe = X1**
- **BW Limit and Invert will remain Off**

The HORIZONTAL control (Time/Div) and the TRIGGER control should be set by default

HORIZONTAL menu	TRIGGER menu
➢ Main ➢ Level	➢ Type = Edge ➢ Source = CH 1 ➢ Slope = Rising ➢ Mode = Auto ➢ Coupling = DC

It is possible to jump between menus just by pressing the button to call them.

- If by mistake parameters were changed and the measurement become impossible then by pressing [DEFAULT SETUP] it is possible to start all over

- There is a [HELP] button that accesses the help screen (it needs 20 second to load.) There is an INDEX. To scroll up or down use the HORIZONTAL POSITION control

At the top of CH 1 control area there is a knob with the legend "POSITION." As soon as it is turned a text appears on the bottom-left corner of the screen with a reference of the trace position. By default is in the zero position. **Make sure the trace is in the zero position**

Above the CH 1 connector is the VOLT/DIV control for CH 1. By turning it left and right the Volt/Div setting changes. The setting appears in the bottom-left of the screen. **Set CH 1 in 1** V

Turn the **DC power supply** ON and set the **output at 1.5 volts**.

Connect the scope probe **to** the **+** lead of **the power supply** and the GND side of the probe to the **-** lead.

Set the Volt/Div control in 1 V.

Switch the Coupling from Ground to DC.

What did you see? _____

Increase the power supply output to 3 volts

What has happened in the screen? _____

Repeat the whole procedure but with the scope Coupling set in AC

What had happened? _____

[When connecting through the AC, there is a cap connected in series with the probe; what makes that only varying voltages can pass. This is called a "filter", since AC will pass and DC will not]

Turn OFF everything.

PART II

ABCs of Function Generators

Basically, a Function Generator (FG) is an AC source. Type of wave, amplitude and frequency can be set and adjusted. Often it has a Frequency-meter that can be used as a counter as well. The levels of current that a FG is able to provide is very low

In this lab is used a FG ELENCO GF-8056. The User Manual can be downloaded from the Internet.

Three types of waves can be obtained from a FG: Sine wave, Triangular, and Square. DC Offsets can be added besides other characteristics.

The amplitude can be set with the AMPLITUDE control. The maximum output is 20 V p-p

The frequency can be set by a combination of three controls
There is a "macro" selector that allows selecting between Hertz and Kilo-Hertz
There is a decade selector that allows selecting ranges: 1, 10, 100, and 1000
There is a fine adjustment control that allows selecting a particular frequency.

I.E.:

To set 1 kHz
Choose kHz – X10 – Move the knob until read in the frequency-meter 1.000

To set 400 Hz
Choose kHz – X1 or X10 – Move the knob to the left. As soon as it is bellow 1 kHz the indicator (front LED) will switch from kHz to Hz although the setting is kHz. The frequency-meter will read 400.0

Insert the leads of the oscilloscope and the generator in their respective ports.

Oscilloscope: Vertical Channel 1 and set the probe in X1 (no attenuation).
Generator: Standard wave output

Connect directly the output from the function generator (the red terminal) to the input of the oscilloscope
Connect the generator's black lead with the grounded lead of the oscilloscope.

Set CH 1's coupling in DC and the FG is sine-wave – 1 kHz, and the amplitude knob turned at 9:00 (more or less)

About the vertical's "Coupling"

a) DC stands for "direct coupling." On the DC position you will see the DC (direct current) component of a signal with the AC component, or you will be able to read pure DC levels of voltage; in other words the input signal will be seen "as is."

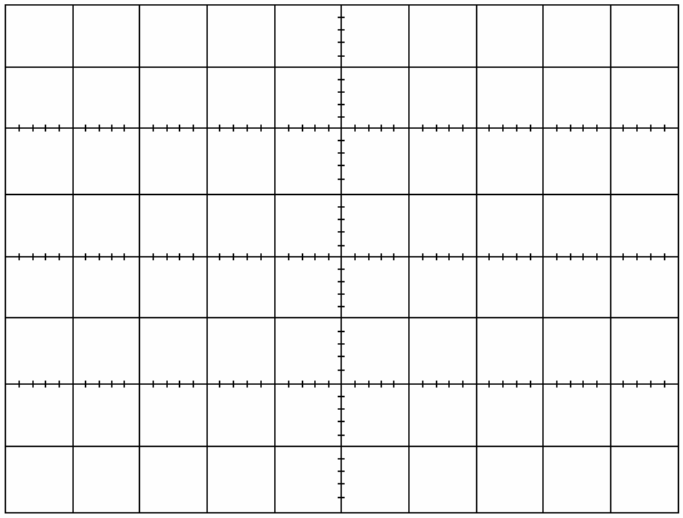
b) On the AC position you will see only the pure AC component of a signal connected to that input. The DC component is filtered by a capacitor

c) On the GND position you will ground the input port internally (it will not ground the source of the signal).

Turn your Volt/Div and Sec/Div controls until one or two waves are displayed in the screen

> [*!*] You should have a smooth and steady sine wave on your screen. If you do not have a steady image or you do not have an image at all, please call your instructor to help you perform other necessaries adjustments.

Please carefully draw the screen with the image making sure to keep proportions and details. Please distinguish in this drawing total amplitude and period of the signal with its values in volts and seconds. The quality of the drawing is very important. Verify that the measurement can be reproduce from the picture based on the recorded setting



Setting		Measurements	
V/Div		Vpp	
Time / / Div		T	

Using the bench DMM in V~ (AC) increase the signal amplitude until the DMM reads something around 5 V, then increase 10 times the frequency range on the FG. Now it should not be anything readable in the screen.

Readjust your Scope settings in order to visualize the new signal.

Read from the screen Amplitude (V p-p) and Period (T).

Setting		Measurements	
V/Div		V p-p	
Time / / Div		T	

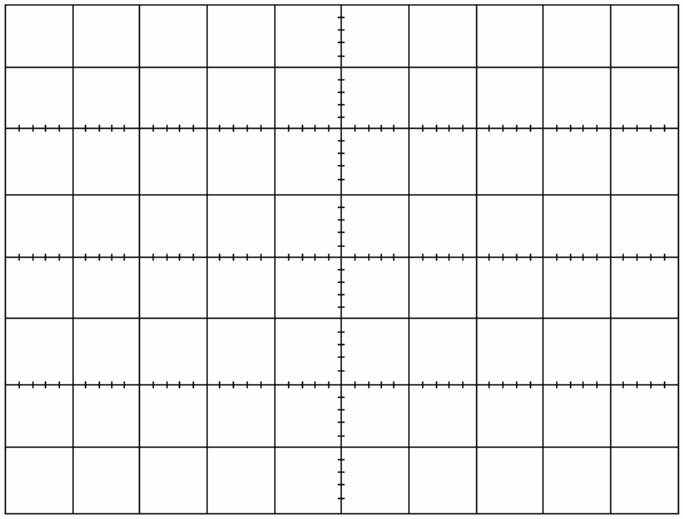
The new value of the amplitude must be 2.82 times higher than the DMM voltage reading, and the new period must be 10 times smaller than the former signal.

What you read in the DMM was the effective voltage of the AC sine wave voltage.

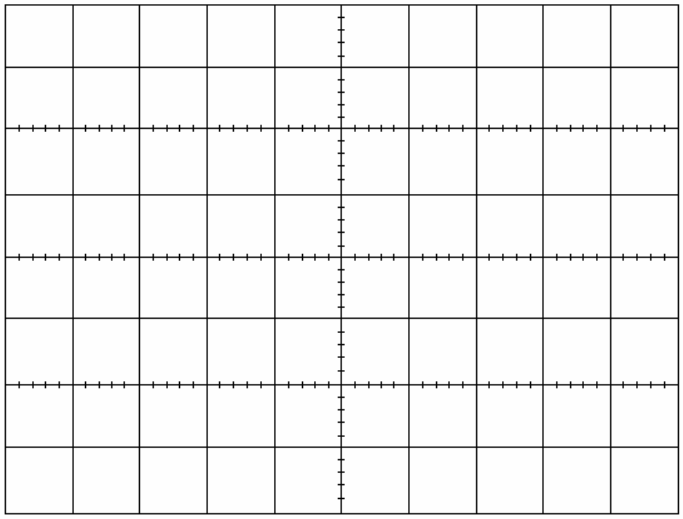
- The peak to peak voltage read from the scope is 2x√2 times bigger (2 times 1.41) than the effective voltage. Remember that the relation between the peak voltage and the effective voltage is √2 (1.41)
- The period has decreased ten times since the frequency has increases ten times. They are reciprocal.

Ask your instructor to set for you a new signal.

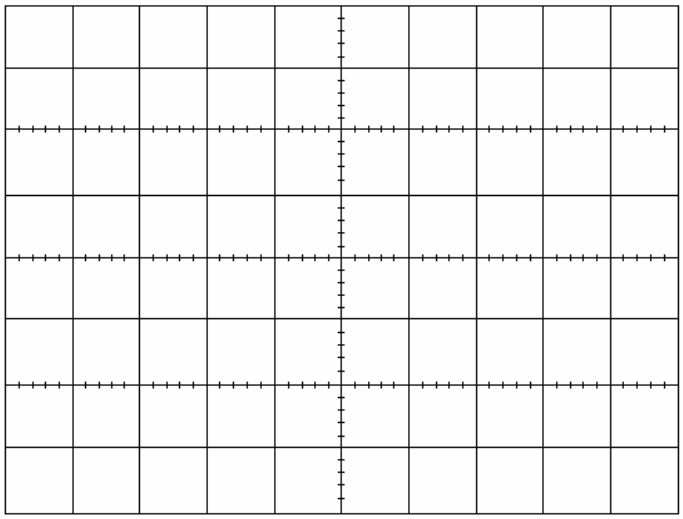
Draw an accurate picture of the screen in the same manner than before. After you find the right settings and having measured amplitude and period, call your instructor and show your results. This procedure will be repeated 6 times and graded based on your graphics and answers.



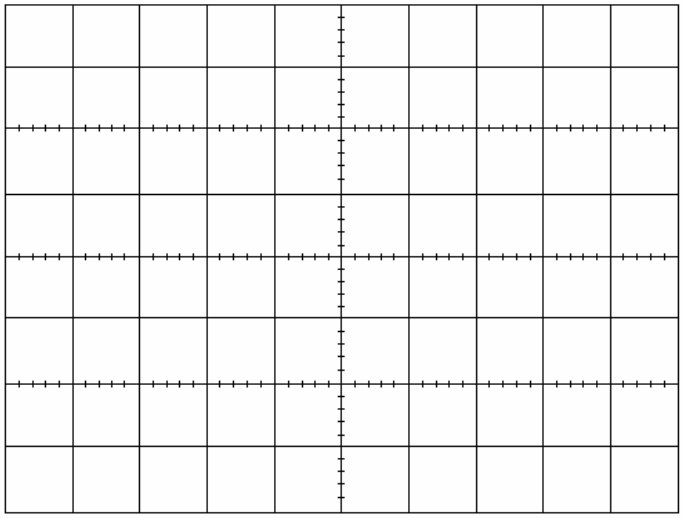
Setting		Measurements	
V/Div		Vpp	
Time / / Div		T	



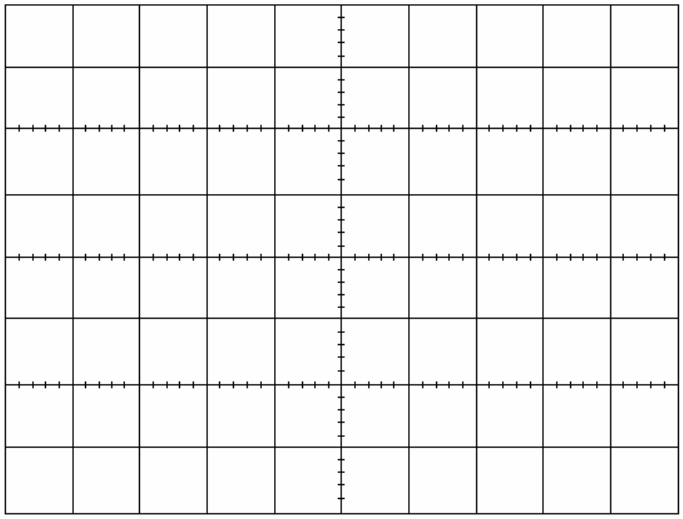
Setting		Measurements	
V/Div		Vpp	
Time / / Div		T	



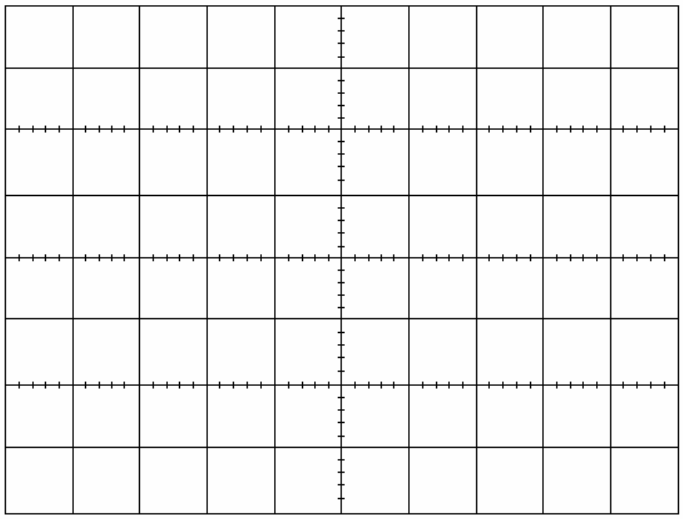
Setting		Measurements	
V/Div		Vpp	
Time / / Div		T	



Setting		Measurements	
V/Div		Vpp	
Time / / Div		T	



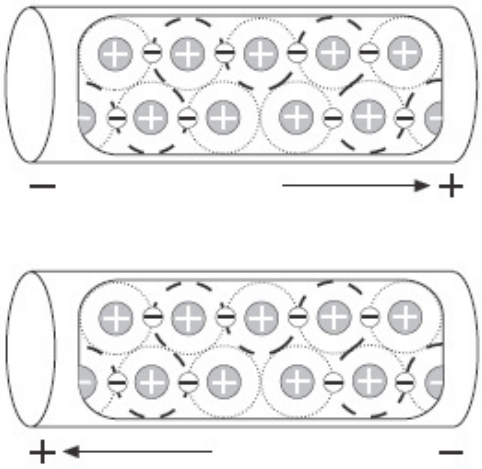
Setting		Measurements	
V/Div		Vpp	
Time / / Div		T	



Setting		Measurements	
V/Div		Vpp	
Time / / Div		T	

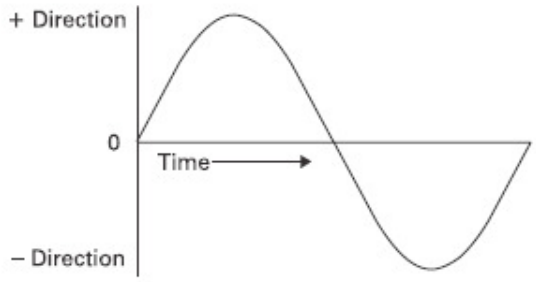
Introduction to AC

The supply of current for electrical devices may come from a direct current source (DC), or an alternating current source (AC). In direct current electricity, electrons flow continuously in one direction from the source of power through a conductor to a load and back to the source of power. The voltage in direct current remains constant. DC power sources include batteries and DC generators. In alternating current an AC generator is used to make electrons flow first in one direction then in another. Another name for an AC generator is an alternator. The AC generator reverses terminal polarity many times a second. Electrons will flow through a conductor from the negative terminal to the positive terminal, first in one direction then another.



AC sine wave

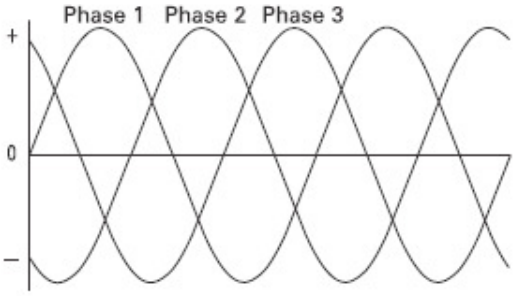
Alternating voltage and current vary continuously. The graphic representation for AC is a sine wave. A sine wave can represent current or voltage. There are two axes. The vertical axis represents the direction and magnitude of current or voltage. The horizontal axis represents time.



When the waveform is above the time axis, current is flowing in one direction. This is referred to as the positive direction. When the waveform is below the time axis, current is flowing in the opposite direction. This is referred to as the negative direction. A sine wave moves through a complete rotation of 360 degrees, which is referred to as one cycle. Alternating current goes through many of these cycles each second. The unit of measurement of cycles per second is hertz. In the United States alternating current is usually generated at 60 hertz.

Single-phase and three-phase AC power

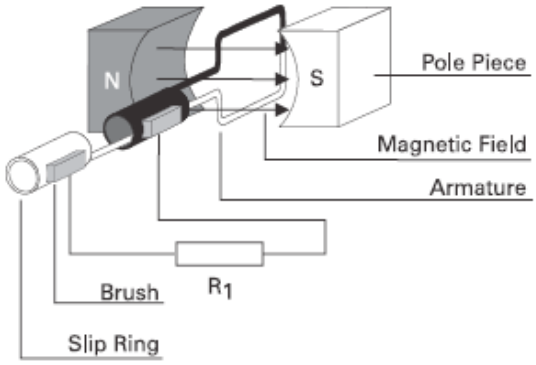
Alternating current is divided into single-phase and three-phase types. Single-phase power is used for small electical demands such as found in the home. Three-phase power is used where large blocks of power are required, such as found in commercial applications and industrial plants. Single-phase power is shown in the above illustration. Three-phase power, as shown in the following illustration, is a continuous series of three overlapping AC cycles. Each wave represents a phase, and is offset by 120 electrical degrees.



AC Generators

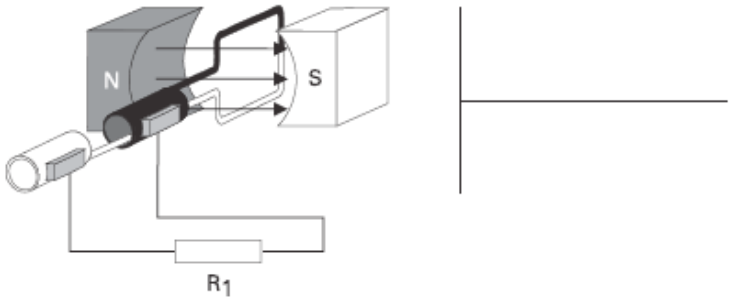
Basic generator

A basic generator consists of a magnetic field, an armature, slip rings, brushes and a resistive load. The magnetic field is usually an electromagnet. An armature is any number of conductive wires wound in loops which rotates through the magnetic field. For simplicity, one loop is shown. When a conductor is moved through a magnetic field, a voltage is induced in the conductor. As the armature rotates through the magnetic field, a voltage is generated in the armature which causes current to flow. Slip rings are attached to the armature and rotate with it. Carbon brushes ride against the slip rings to conduct current from the armature to a resistive load.



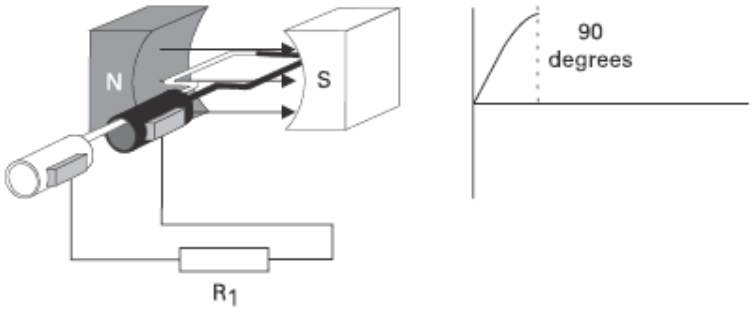
Basic generator operation

An armature rotates through the magnetic field. At an initial position of zero degrees, the armature conductors are moving parallel to the magnetic field and not cutting through any magnetic lines of flux. No voltage is induced.



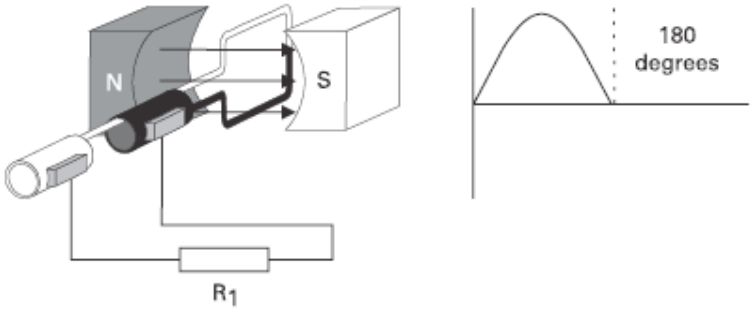
Generator operation from zero to 90 degrees

The armature rotates from zero to 90 degrees. The conductors cut through more and more lines of flux, building up to a maximum induced voltage in the positive direction.



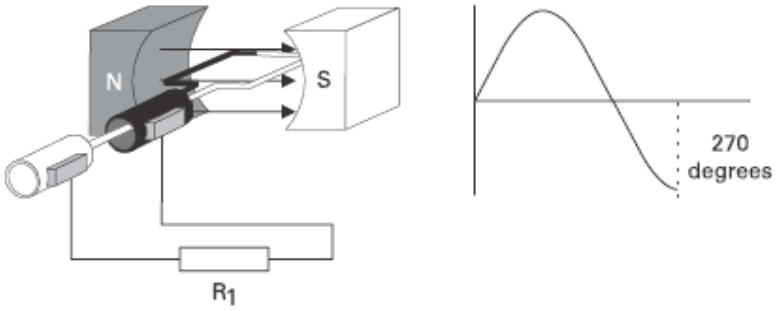
Generator operation from 90 to 180 degrees

The armature continues to rotate from 90 to 180 degrees, cutting less lines of flux. The induced voltage decreases from a maximum positive value to zero.



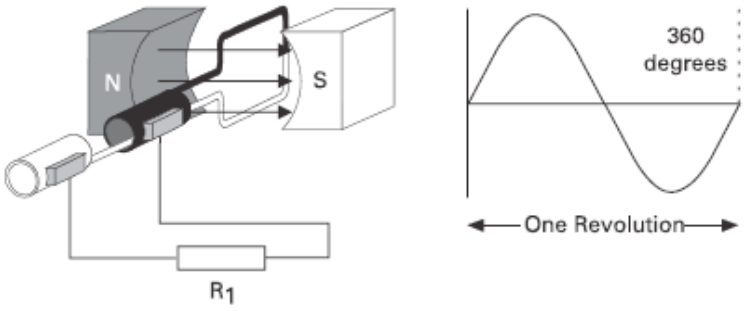
Generator operation from 180 to 270 degrees

The armature continues to rotate from 180 degrees to 270 degrees. The conductors cut more and more lines of flux, but in the opposite direction. Voltage is induced in the negative direction building up to a maximum at 270 degrees.



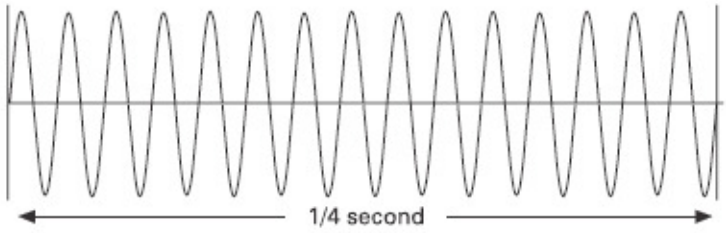
Generator operation from 270 to 360 degrees

The armature continues to rotate from 270 to 360 degrees. Induced voltage decreases from a maximum negative value to zero. This completes one cycle. The armature will continue to rotate at a constant speed. The cycle will continuously repeat as long as the armature rotates.



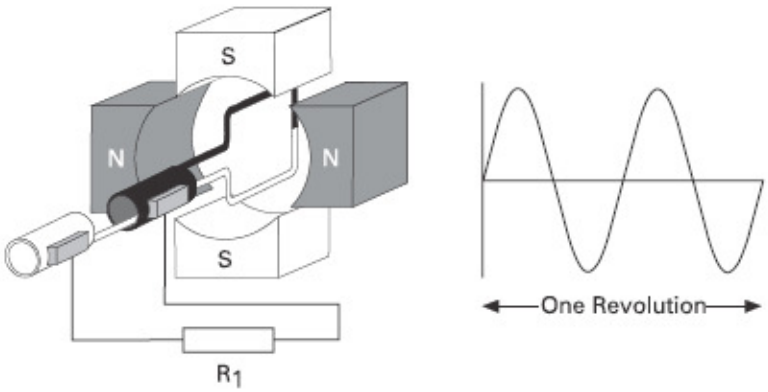
Frequency

The number of cycles per second made by voltage induced in the armature is the frequency of the generator. If the armature rotates at a speed of 60 revolutions per second, the generated voltage will be 60 cycles per second. The accepted term for cycles per second is hertz. The standard frequency in the United States is 60 hertz. The following illustration shows 15 cycles in 1/4 second which is equivalent to 60 cycles in one second.



Four-pole AC generator

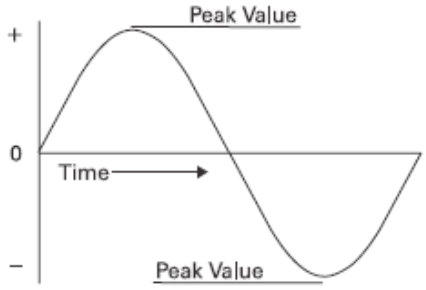
The frequency is the same as the number of rotations per second if the magnetic field is produced by only two poles. An increase in the number of poles, would cause an increase in the number of cycles completed in a revolution. A two-pole generator would complete one cycle per revolution and a four-pole generator would complete two cycles per revolution. An AC generator produces one cycle per revolution for each pair of poles.



Voltage and Current

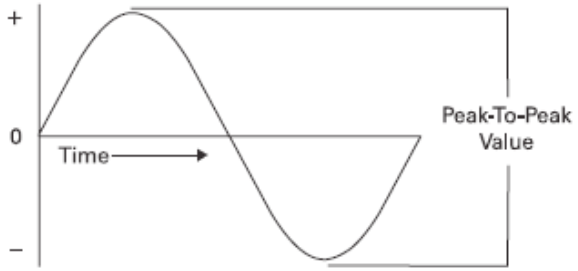
Peak value

The sine wave illustrates how voltage and current in an AC circuit rises and falls with time. The peak value of a sine wave occurs twice each cycle, once at the positive maximum value and once at the negative maximum value.



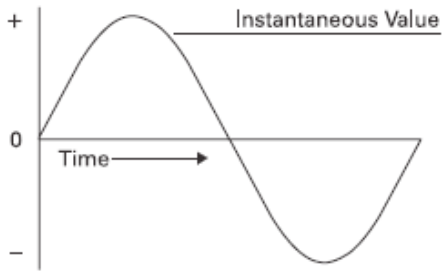
Peak-to-peak value

The value of the voltage or current between the peak positive and peak negative values is called the peak-to-peak value.



Instantaneous value

The instantaneous value is the value at any one particular time. It can be in the range of anywhere from zero to the peak value.



Calculating instantaneous voltage

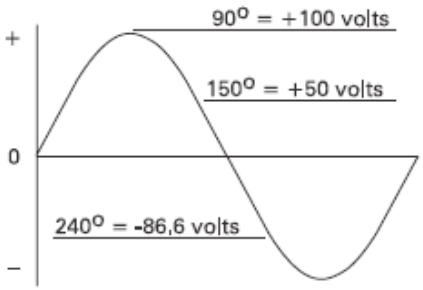
The voltage waveform produced as the armature rotates through 360 degrees rotation is called a sine wave because instantaneous voltage is related to the trigonometric function called sine (sin θ = sine of the angle). The sine curve represents a graph of the following equation:

$$e = E_{peak} \times \sin \theta$$

Instantaneous voltage is equal to the peak voltage times the sine of the angle of the generator armature. The sine value is obtained from trigonometric tables. The following table reflects a few angles and their sine value.

Angle	Sin θ	Angle	Sin θ
30 degrees	.5	210 degrees	-.5
60 degrees	.866	240 degrees	-.866
90 degrees	1	270 degrees	-1
120 degrees	.866	300 degrees	-.866
150 degrees	.5	330 degrees	-.5
180 degrees	0	360 degrees	0

The following example illustrates instantaneous values at 90, 150, and 240 degrees. The peak voltage is equal to 100 volts. By substituting the sine at the instantaneous angle value, the instantaneous voltage can be calculated.



Any instantaneous value can be calculated. For example:

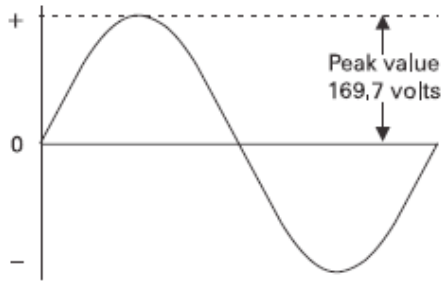
$240°$

$e = 100 \times -.866$

$e = -86.6 \text{ volts}$

Effective value of an AC sine wave

Alternating voltage and current are constantly changing values. A method of translating the varying values into an equivalent constant value is needed. The effective value of voltage and current is the common method of expressing the value of AC. This is also known as the RMS (root-mean-square) value. If the voltage in the average home is said to be 120 volts, this is the RMS value. The effective value figures out to be 0.707 times the peak value.



169.7 V_{peak} x .707 = 120 Vrms

The effective value of AC is defined in terms of an equivalent heating effect when compared to DC. One RMS ampere of current flowing through a resistance will produce heat at the same rate as a DC ampere.

For purpose of circuit design, the peak value may also be needed. For example, insulation must be designed to withstand the peak value, not just the effective value. It may be that only the effective value is known. To calculate the peak value, multiply the effective value by 1.41. For example, if the effective value is 100 volts, the peak value is 141 volts.

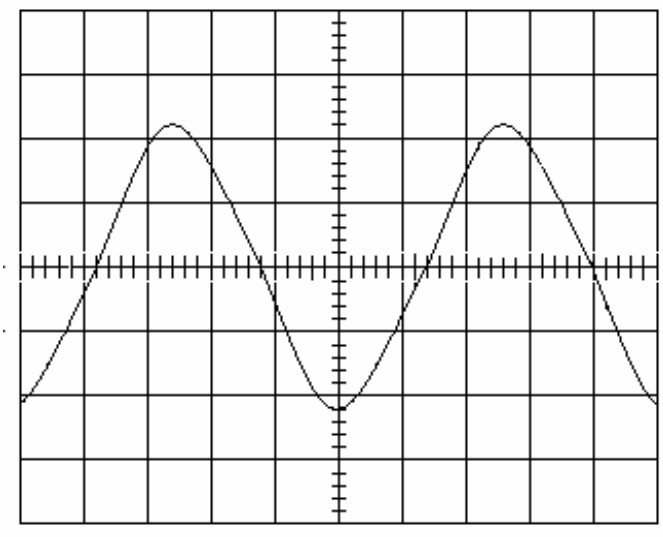
Review 8

1. The graphic representation of AC voltage or current values over a period of time is a _____ _____ .
2. Each phase of three phase AC power is offset by _____ degrees.
3. An AC generator produces _____ cycle per revolution for each pair of poles.
4. What is the instantaneous voltage at 240 degrees for a peak voltage of 150 volts?
5. What is the effective voltage for a peak voltage of 150 volts?

Questions – AC and Scopes – SHOW YOUR WORK

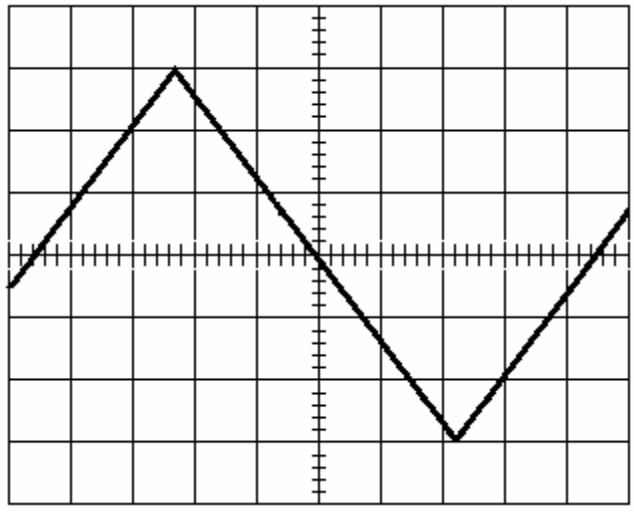
Based on the pictures determinate V p-p , T, and also F and V_{RMS} **(only for sine waves cases)**

1)



Settings		Measurements	
V/Div	2 V	V p-p	V
Time / / Div	2 mS	T	mS
Calculations			
f =	KHz	E eff =	V

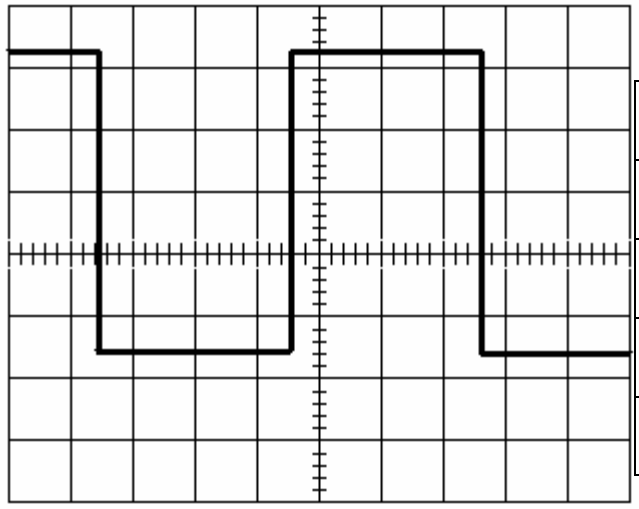
2)



Settings		Measurements	
V/Div	50 mV	V p-p	mV
Time / / Div	50 µS	T	µS
Calculations			
f = KHz			

OVER PLEASE →

3)



Settings		Measurements	
V/Div	1 V	V p-p	V
Time / / Div	0.2 mS	T	mS
Calculations			
f = KHz			

WEEKS 9 & 10

Notes

Notes

Notes

Notes

RL & RC Circuits in AC

Introduction

You already have worked with capacitors and coils, and verified how electric and magnetic fields can be manipulated.

We have transferred energy using magnetic fields around coils and accumulated energy as electric field into capacitors.

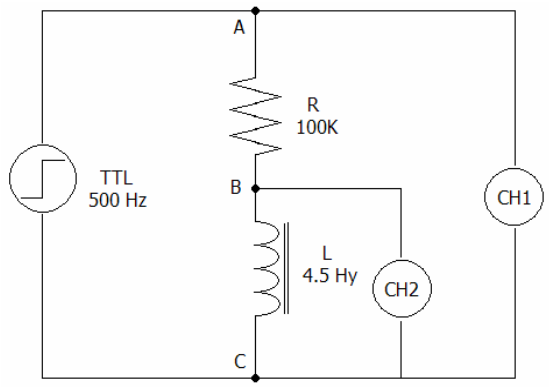
In the first part of this lab, using a square wave generator (from the TTL output of the FG) that behaves as a fast switch, you will see how RL and RC circuits behave during the ON – OFF transitions, when coils and capacitors have to build their fields, and OFF – ON transitions when those fields collapse and energy is retrieved.

In the second part of this lab, by means of using the FG as a sine wave generator, we'll see how this swing of energy, building fields and then collapsing them following the variation of the source (the FG), makes voltage and current shift phases.

Important things to be remembered

1. **An oscilloscope is a graphic voltmeter**
2. Since resistors' resistance do not depend on anything but the intrinsic characteristic of the material that makes the component, voltage drop across resistors are directly tied to the current flowing through a resistor. This fact will be demonstrated along this lab, but it is important to stress it and to keep it in mind due to the impossibility to graph the current. So, **when watching a voltage drop across a resistor by using the scope, remember, the current is doing exactly the same. Just divide the voltage reading by the resistance and the level of current will be known. Current's phase will the same that the resistor's voltage drop phase.**

Circuits RL – DC transients



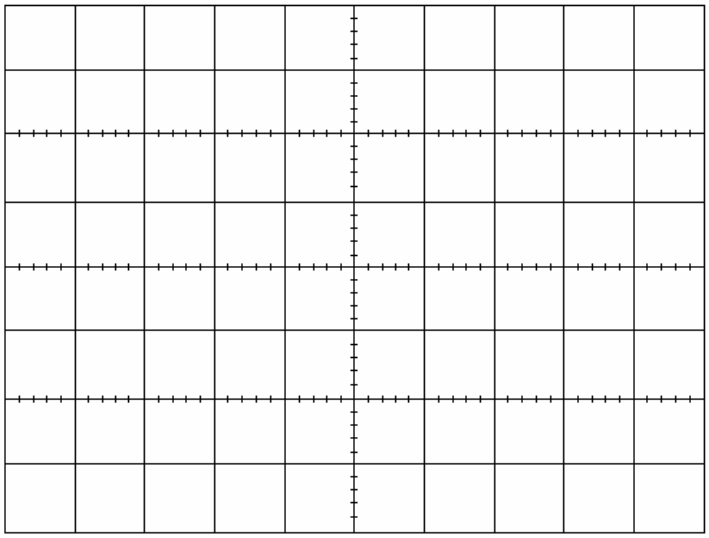
Build the next circuit. Connect the red lead of the FG to point A.

By using both channels of the oscilloscope display the input voltage and the drop of voltage across the coil.

Set both channels of the oscilloscope in DC coupling

Pay attention which grid-line in the screen is the zero reference line for each channel. What is above the chosen line is positive and what is below is negative

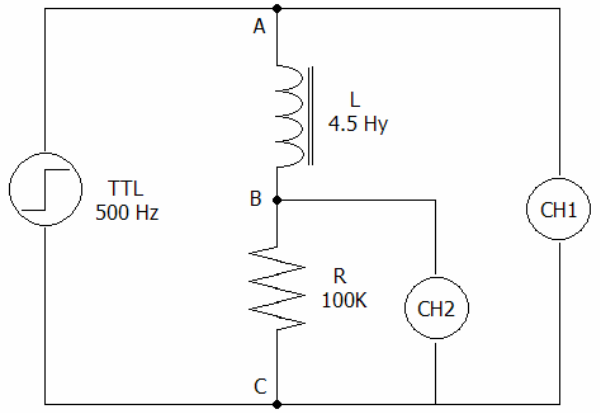
Please, draw the screen. Use different colors to identify each channel.



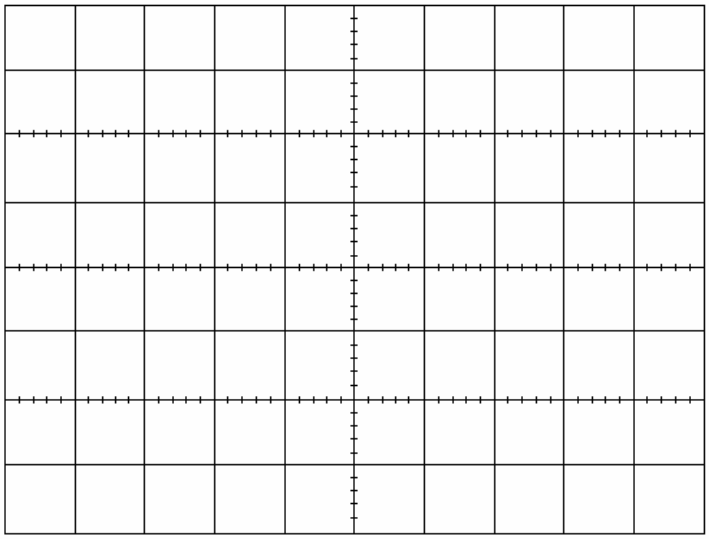
	V/Div		Time/Div
Setting	CH1	CH2	
Measurement			

Swap the components of the circuit as it is shown in the next schematic. Keep the red lead of the FG connected to point A

.



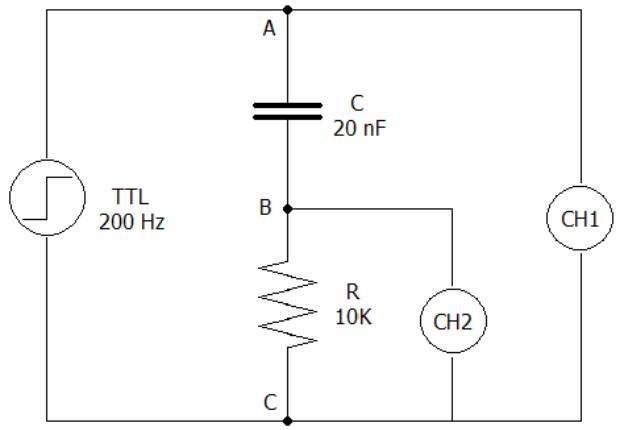
Please, draw the screen. Use different colors to identify each channel.



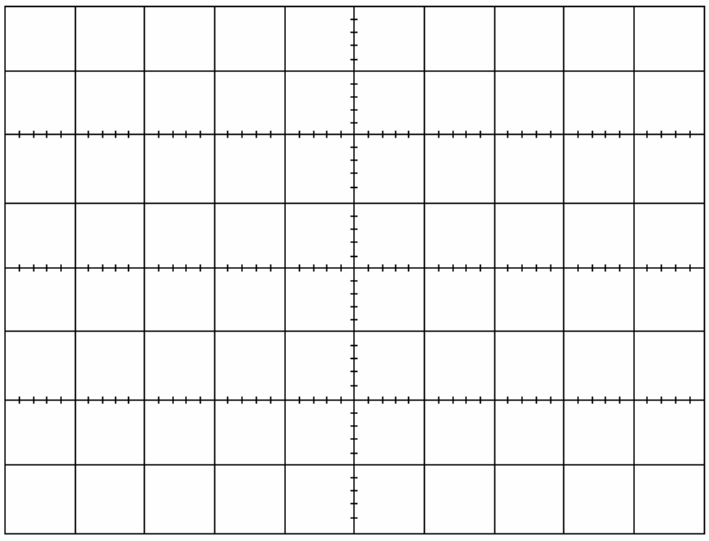
	V/Div		Time/Div
Setting	CH1	CH2	
Measurement			

Circuits RC – DC transients

Build the next circuit. Connect the red lead of the FG to point A.

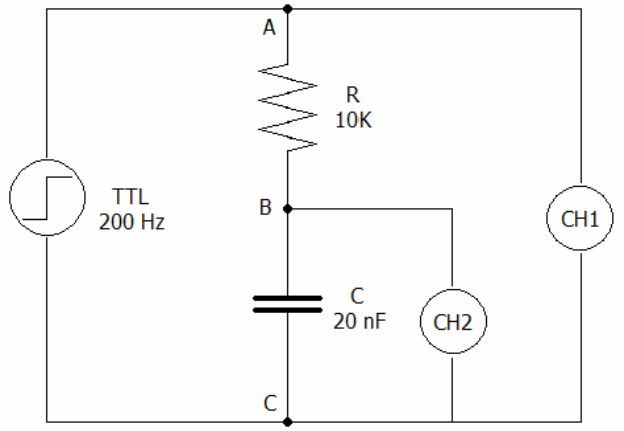


Please, draw the screen. Use different colors to identify each channel.

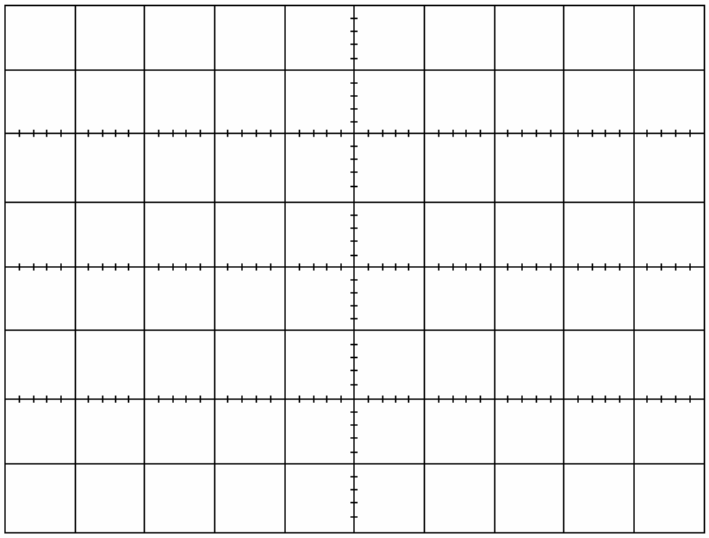


	V/Div		Time/Div
Setting	CH1	CH2	
Measurement			

Swap the components of the circuit as it is shown in the next schematic. Keep the red lead of the FG connected to point A.



Please, draw the screen. Use different colors to identify each channel.

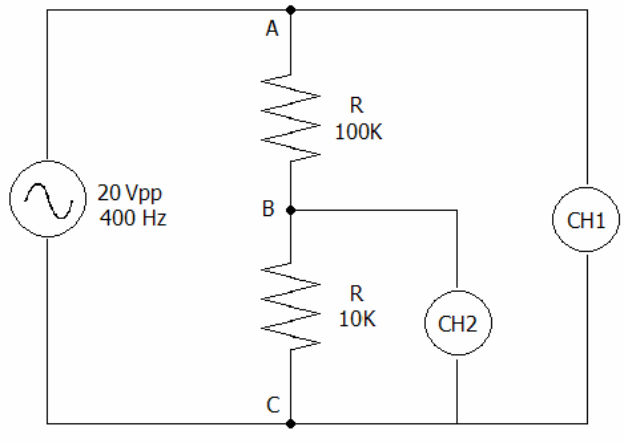


	V/Div		Time/Div
Setting	CH1	CH2	
Measurement			

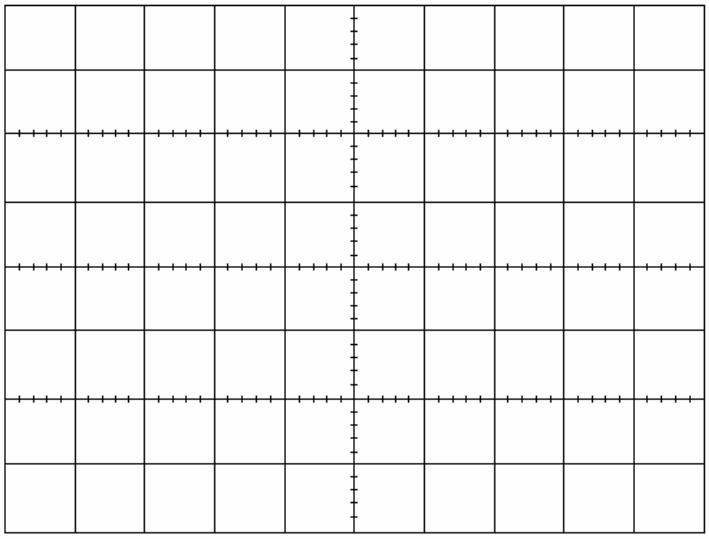
Pure resistive circuits in AC

For all the rest of the experiments to come in this lab, set both channels of the oscilloscope in AC coupling.

Build the next circuit. Connect the red lead of the FG to point A



Please, draw the screen. Use different colors to identify each channel.



		V/Div	Time/Div
Setting	CH1	CH2	
Measurement	Vpp	Vpp	T

Please measure the time difference between both waves

Time diff =

Make the relation → Time diff ÷ Period = _____

A zero means that there is no shift between the input voltage and the voltage drop measured across the 10K resistor, and therefore there is not shift between the input voltage and the current that is flowing through the resistor.

Since this is a series circuit, the current flowing one component is the same for the other component. Anyway, just for the sake of making sure that there is no shift lets swap the components and measure the time difference again

Did the Time diff change? YES NO

Swap the components again, coming back to the circuit in the former page.

Disconnect both channels of the oscilloscope and using your DMM read the voltage drop between points B and C (across 10K).

$\mathscr{E}_{eff\text{-BC}} =$

Using your DMM read the current in the circuit. $\mathscr{I}_{eff} =$

Using the measurements verify Ohm's law $\mathscr{I}_{\text{eff}} = \mathscr{E}_{eff\text{-BC}} \div 10\text{K}.$

_____

Using your DMM read the voltage between points A and C (total voltage) and A and B (voltage drop across 100K)

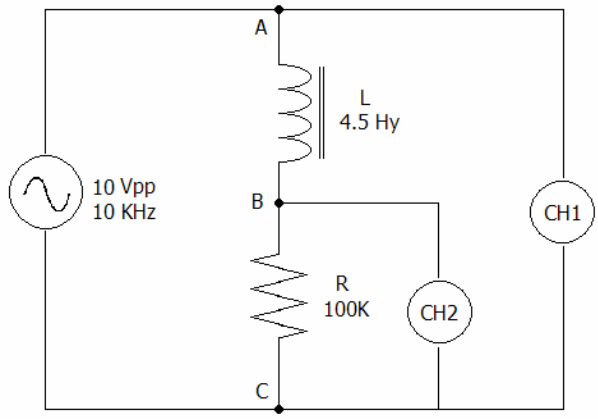
Verify KVL

$\mathscr{E}_{eff\text{-AC}} = \mathscr{E}_{eff\text{-AB}} + \mathscr{E}_{eff\text{-BC}}$ _____ KVL

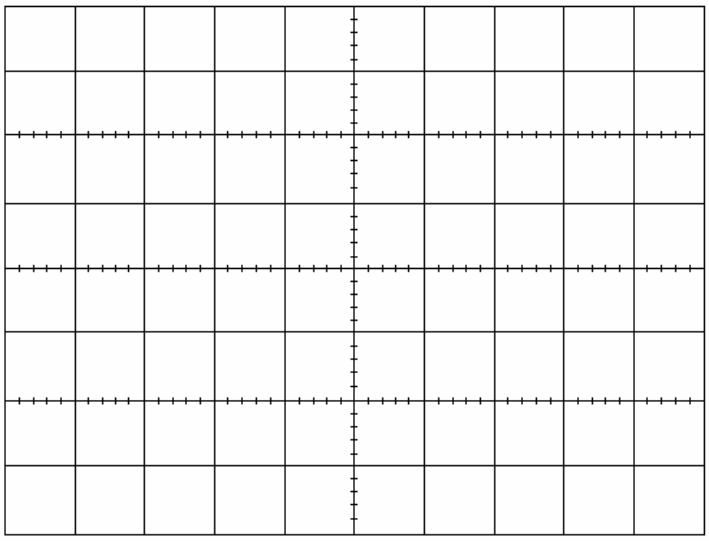
$100\text{K} \div 10\text{K} = \mathscr{E}_{eff\text{-AB}} \div \mathscr{E}_{eff\text{-BC}}$_____ voltage divider ratio

RL circuits in AC (sine wave inputs)

Build the next circuit. Connect the red lead of the FG to point A



Please, draw the screen. Use different colors to identify each channel.



	V/Div		Time/Div
Setting	CH1	CH2	
Measurement	Vpp	Vpp	T

What is seen in the screen is the voltage from the source in channel 1 and the voltage drop across the resistor in channel 2.
Notice that the voltage drop across the resistor is many times smaller than the source, which means that the main drop of voltage is occurring in the coil.
Therefore this circuit is behaving as a strongly inductive circuit since the voltage drop across the coil is more significant than the voltage drop across the resistor.
Since resistors do not generate phase shift between current and voltage, the voltage drop across the resistor is in perfect phase with the total current of the circuit (notice that this is a series circuit and current is the same for both components) therefore the phase difference between CH1 trace (Total voltage applied to the circuit) and CH2 trace (resistor's voltage drop) is showing a close picture of an inductive circuit response to a sine wave input where voltage and current get shifted with the current lagging behind the voltage.

As it can be seen, when the voltage applied (represented in CH1) is at its maximum, the voltage drop across the resistor is going towards zero and vise versa. **The voltage drop across the resistor is showing the behavior of the current. Current follows Voltage, or Current lags behind Voltage.**

Please measure the time difference between both waves

Time diff =

Make the relation → Time diff ÷ Period = _____

As it was said, a zero means no-shift, but in this case the result was something between 0 and 0.25.

0.25 is the occurrence of a pure inductive circuit where current and voltage shift 90º. Not having 0.25 is the sign of a compound circuit where the resistive component of the circuit moderates the effects of the reactive component.
To find out what is the shift in electrical degrees, just multiply the Time diff – Period relation by 90 and divide by 0.25
Calculate the shift between voltage and current: Φ = _____ º

Measure carefully the voltage (RMS) applied to the circuit and the voltage drop (RMS) across each component and verify KVL

$\mathscr{E}_i = \mathscr{E}_L + \mathscr{E}_R$	

Show your measurements to your instructor to discuss the result

- -

Decrease the frequency ten times.
Take note of the new period and time difference, and find the "Time diff to Period" ratio and the shift between voltage and current.

Period T	Time Difference	Time diff ÷ Period	Φ

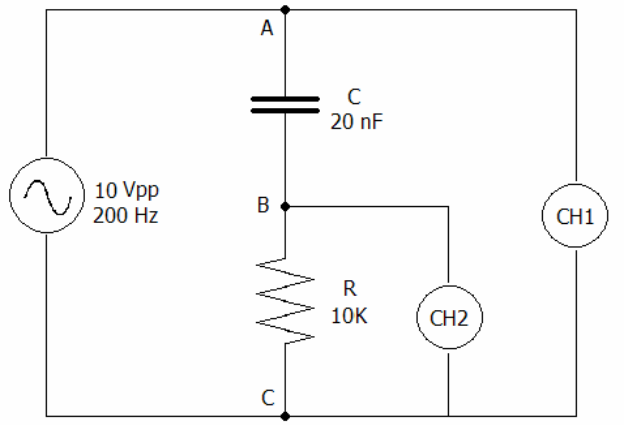
Decrease the frequency ten times again.

Period T	Time Difference	Time diff ÷ Period	Φ

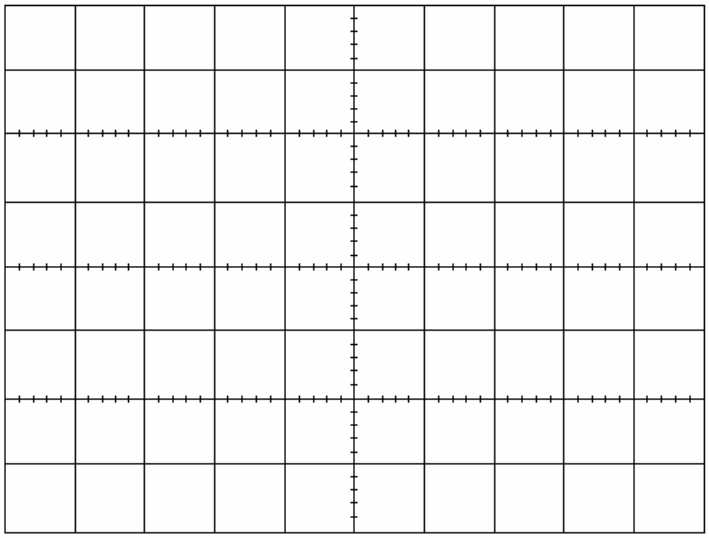
It is easy to see that as frequency slows down
a) The voltage drop across the resistor increases, and
b) The phase difference decreases until become negligible. At this point the reactive component of the circuit is negligible, and the circuit is behaving as a strongly resistive circuit

RC circuits in AC (sine wave inputs)

Build the next circuit. **When setting frequency, use the 1K range in the FG**. Connect the red lead of the FG to point A



Please, draw the screen. Use different colors to identify each channel.



		V/Div	Time/Div
Setting	CH1	CH2	
Measurement	Vpp	Vpp	T

What is seen in the screen is the voltage from the source in channel 1 and the voltage drop across the resistor in channel 2.
Notice that the voltage drop across the resistor is many times smaller than the source what means that the main drop of voltage is occurring in the cap.
Therefore this circuit is behaving as a strongly capacitive circuit since the voltage drop across the cap is more significant than the voltage drop across the resistor.
Since resistors do not generate phase shift between current and voltage, the voltage drop across the resistor is in perfect phase with the total current of the circuit (notice that this is a series circuit and current is the same for both components) therefore the phase difference between CH1 trace (Total voltage applied to the circuit) and CH2 trace (resistor's voltage drop) is showing a close picture of an capacitive circuit response to a sine wave input where voltage and current get shifted with the current leading forth the voltage.

As it can be seen, when the voltage applied (represented in CH1) is at its maximum, the voltage drop across the resistor is going towards zero and vise versa. **The voltage drop across the resistor is showing the behavior of the current. Current happens before Voltage, or Current leads Voltage.**

Please measure the time difference between both waves

Time diff =

Make the relation → Time diff ÷ Period = _____

As it was said, a zero means no-shift, but in this case the result was something between 0 and 0.25.

0.25 is the occurrence of a pure capacitive circuit where current and voltage shift 90º. Not having 0.25 is the sign of a compound circuit where the resistive component of the circuit moderates the effects of the reactive component.
To find out what is the shift in electrical degrees, just multiply the Time diff – Period relation by 90 and divide by 0.25
Calculate the shift between voltage and current: Φ = _____ º

Measure carefully the voltage (RMS) applied to the circuit and the voltage drop (RMS) across each component and verify KVL

$\mathscr{E}_i = \mathscr{E}C + \mathscr{E}R$	

Show your measurements to your instructor to discuss the result

- -

Increase the frequency ten times
Take note of the new period and time difference. Find the new "Time diff to Period" ratio and the shift between voltage and current

Period T	Time Difference	Time diff ÷ Period	Φ

Increase the frequency ten times again.

Period T	Time Difference	Time diff ÷ Period	Φ

It is easy to see that as frequency increases.
a) The voltage drop across the resistor increases, and
b) The phase difference decreases until become negligible. At this point the reactive component of the circuit is negligible, and the circuit is behaving as a strongly resistive circuit

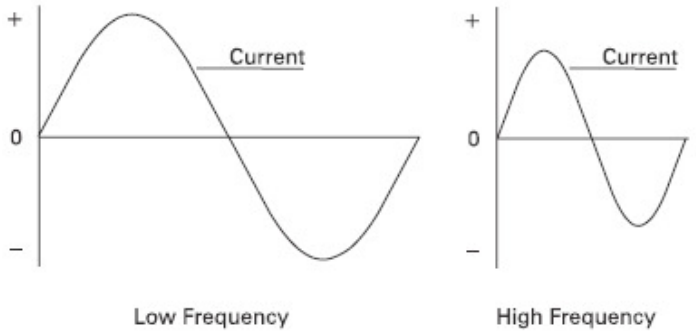
Inductive and Capacitive Reactance

In a purely resistive AC circuit, opposition to current flow is called resistance. In an AC circuit containing only inductance, capacitance, or both, opposition to current flow is called reactance. Total opposition to current flow in an AC circuit that contains both reactance and resistance is called impedance designated by the symbol "Z". Reactance and impedance are expressed in ohms.

Inductive reactance

Inductance only affects current flow when the current is changing. Inductance produces a self-induced voltage (counter emf) that opposes changes in current. In an AC circuit, current is changing constantly. Inductance in an AC circuit, therefore, causes a continual opposition. This opposition to current flow is called inductive reactance, and is designated by the symbol X_L.

Inductive reactance is dependent on the amount of inductance and frequency. If frequency is low current has more time to reach a higher value before the polarity of the sine wave reverses. If frequency is high current has less time to reach a higher value. In the following illustration, voltage remains constant. Current rises to a higher value at a lower frequency than a higher frequency.



The formula for inductive reactance is:

$$X_L = 2\pi fL$$
$$X_L = 2 \times 3.14 \times frequency \times inductance$$

In a 60 hertz, 10 volt circuit containing a 10 mh inductor, the inductive reactance would be:

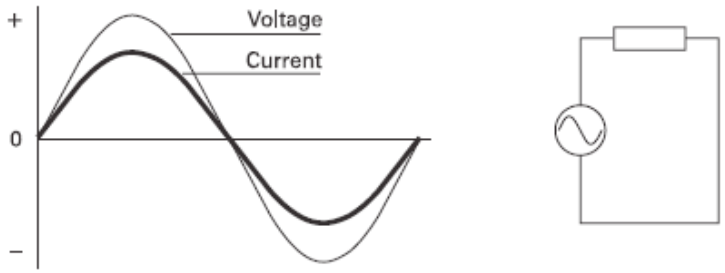
$$X_L = 2\pi fL$$
$$X_L = 2 \times 3.14 \times 60 \times .010$$
$$X_L = 3.768\ \Omega$$

Once inductive reactance is known, Ohm's Law can be used to calculate reactive current.

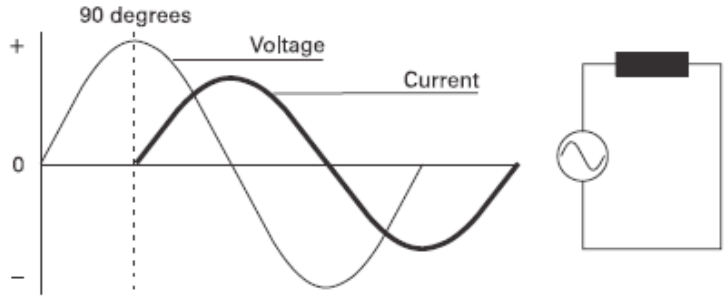
$$I = \frac{E}{Z}$$
$$I = \frac{10}{3.768}$$
$$I = 2.65\ amps$$

Phase relationship between current and voltage in an inductive circuit

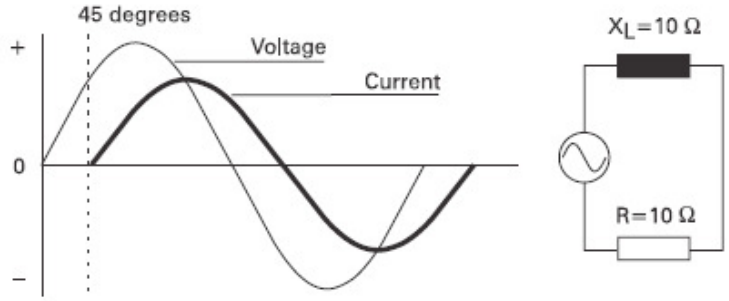
Current does not rise at the same time as the source voltage in an inductive circuit. Current is delayed depending on the amount of inductance. In a purely resistive circuit, current and voltage rise and fall at the same time. They are said to be "in phase." In this circuit there is no inductance, resistance and impedance are the same.



In a purely inductive circuit, current lags behind voltage by 90 degrees. Current and voltage are said to be "out of phase". In this circuit, impedance and inductive reactance are the same.



All inductive circuits have some amount of resistance. AC current will lag somewhere between a purely resistive circuit, and a purely inductive circuit. The exact amount of lag depends on the ratio of resistance and inductive reactance. The more resistive a circuit is, the closer it is to being in phase. The more inductive a circuit is, the more out of phase it is. In the following illustration, resistance and inductive reactance are equal. Current lags voltage by 45 degrees.



Calculating impedance in an inductive circuit

When working with a circuit containing elements of inductance, capacitance, and resistance, impedance must be calculated. Because electrical concepts deal with trigonometric functions, this is not a simple matter of subtraction and addition. The following formula is used to calculate impedance in an inductive circuit:

$$Z = \sqrt{R^2 + X_L{}^2}$$

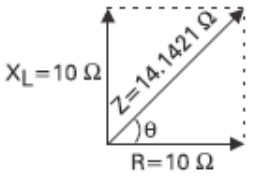
In the circuit illustrated above, resistance and inductive reactance are each 10 ohms. Impedance is 14.1421 ohms. A simple application of Ohm's Law can be used to find total circuit current.

$$Z = \sqrt{10^2 + 10^2}$$
$$Z = \sqrt{200}$$
$$Z = 14.1421\ \Omega$$

Vectors

Another way to represent this is with a vector. A vector is a graphic representation of a quantity that has direction and magnitude. A vector on a map might indicate that one city is 50 miles southwest from another. The magnitude is 50 miles, and the direction is southwest. Vectors are also used to show electrical relationships. As mentioned earlier, impedance (Z) is the total oppositon to current flow in an AC circuit containing resistance, inductance, and capacitance. The following

vector illustrates the relationship between resistance and inductive reactance of a circuit containing equal values of each. The angle between the vectors is the phase angle represented by the symbol θ. When inductive reactance is equal to resistance the resultant angle is 45 degrees. It is this angle that determines how much current will lag voltage.



Capacitive reactance

Capacitance also opposes AC current flow. Capacitive reactance is designated by the symbol X_C. The larger the capacitor, the smaller the capacitive reactance. Current flow in a capacitive AC circuit is also dependent on frequency. The following formula is used to calculate capacitive reactance:

$$X_C = \frac{1}{2\pi fC}$$

Capacitive reactance is equal to 1 divided by 2 times pi, times the frequency, times the capacitance. In a 60 hertz, 10 volt circuit containing a 10 microfarad capacitor the capacitive reactance would be:

$$X_C = \frac{1}{2\pi fC}$$

$$X_C = \frac{1}{2 \times 3.14 \times 60 \times 0.000010}$$

$$X_C = 265.39\ \Omega$$

Once capacitive reactance is known, Ohm's Law can be used to calculate reactive current.

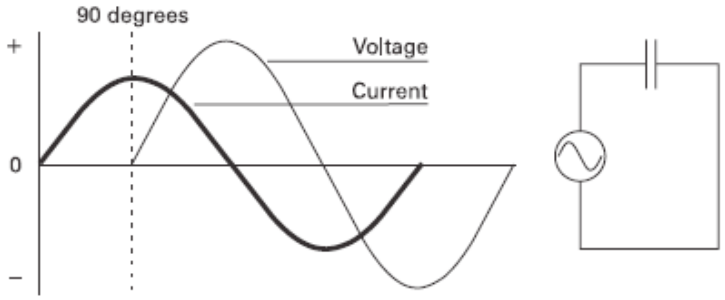
$$I = \frac{E}{Z}$$

$$I = \frac{10}{265.39}$$

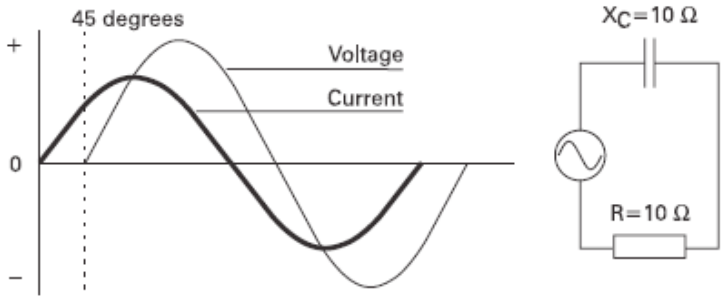
$$I = .0376\ amps$$

Phase relationship between current and voltage in a capacitive circuit

The phase relationship between current and voltage are opposite to the phase relationship of an inductive circuit. In a purely capacitive circuit, current leads voltage by 90 degrees.



All capacitive circuits have some amount of resistance. AC current will lead somewhere between a purely resistive circuit and a purely capacitive circuit. The exact amount of lead depends on the ratio of resistance and capacitive reactance. The more resistive a circuit is, the closer it is to being in phase. The more capacitive a circuit is, the more out of phase it is. In the following illustration, resistance and capacitive reactance are equal. Current leads voltage by 45 degrees.



Calculating impedance in a capacitive circuit

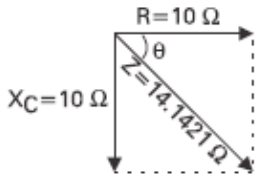
The following formula is used to calculate impedance in a capacitive circuit:

$$Z = \sqrt{R^2 + X_C{}^2}$$

In the circuit illustrated above, resistance and capacitive reactance are each 10 ohms. Impedance is 14.1421 ohms.

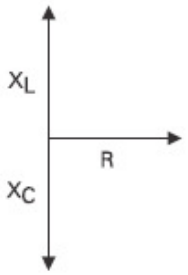
$$Z = \sqrt{10^2 + 10^2}$$
$$Z = \sqrt{200}$$
$$Z = 14.1421\ \Omega$$

The following vector illustrates the relationship between resistance and capacitive reactance of a circuit containing equal values of each. The angle between the vectors is the phase angle represented by the symbol θ. When capacitive reactance is equal to resistance the resultant angle is -45 degrees. It is this angle that determines how much current will lead voltage.



Series R-L-C Circuit

Circuits often contain elements of resistance, inductance, and capacitance. In an inductive AC circuit, current lags voltage by 90 degrees. In a AC capacitive circuit, current leads voltage by 90 degrees. It can be seen that inductance and capacitance are 180 degrees apart. Since they are 180 degrees apart, one element will cancel out all or part of the other element.



An AC circuit is:

- Resistive if X_L and X_C are equal
- Inductive if X_L is greater than X_C
- Capacitive if X_C is greater than X_L

Calculating total impedance in a series R-L-C circuit

The following formula is used to calculate total impedance of a circuit containing resistance, capacitance, and inductance:

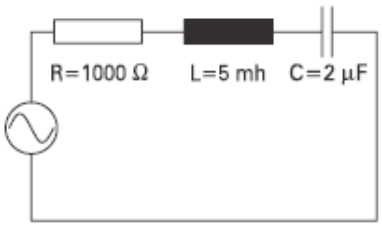
$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

In the case where inductive reactance is greater than capacitive reactance, subtracting X_C from X_L results in a positive number. The positive phase angle is an indicator that the net circuit reactance is inductive, and current lags voltage.

In the case where capacitive reactance is greater than inductive reactance, subtracting X_C from X_L results in a negative number. The negative phase angle is an indicator that the net circuit reactance is capacitive and current leads voltage. In either case, the value squared will result in positive number.

Calculating reactance and impedance in a series R-L-C circuit

In the following 120 volt, 60 hertz circuit, resistance is 1000 Ω, inductance is 5 mh, and capacitance is 2 µF.



To calculate total impedance, first calculate the value of X_L and X_C, then impedance can be calculated.

$$X_L = 2\pi fL$$
$$X_L = 6.28 \times 60 \times .005$$
$$X_L = 1.884\ \Omega$$

$$X_C = \frac{1}{2\pi fC}$$
$$X_C = \frac{1}{6.28 \times 60 \times .000002}$$
$$X_C = 1,327\ \Omega$$

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$
$$Z = \sqrt{1000^2 + (1.884 - 1,327)^2}$$
$$Z = \sqrt{1,000,000 + (-1,325.116)^2}$$
$$Z = \sqrt{1,000,000 + 1,755,932.41}$$
$$Z = \sqrt{2,755,932.41}$$
$$Z = 1,660.1\ \Omega$$

Calculating circuit current in a series R-L-C circuit

Ohm's Law can be applied to calculate total circuit current.

$$I = \frac{E}{Z}$$
$$I = \frac{120}{1,660.1}$$
$$I = .072\ amps$$

Parallel R-L-C Circuit

Calculating impedance in a parallel R-L-C circuit

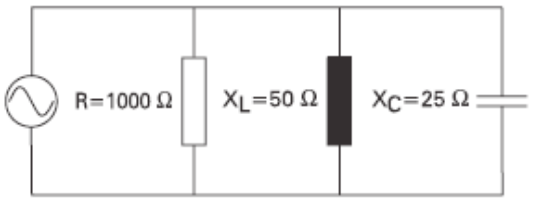
Total impedance (Z_t) can be calculated in a parallel R-L-C circuit if values of resistance and reactance are known. One method of calculating impedance involves first calculating total current, then using the following formula:

$$Z_t = \frac{E_t}{I_t}$$

Total current is the vector sum of current flowing through the resistance plus, the difference between inductive current and capacitive current. This is expressed in the following formula:

$$I_t = \sqrt{I_R^2 + (I_C - I_L)^2}$$

In the following 120 volt, 60 hertz circuit, Capacitive reactance has been calculated to be 25 Ω and inductive reactance 50 Ω. Resistance is 1000 Ω.



A simple application of Ohm's Law will find the branch currents. Remember, voltage is constant throughout a parallel circuit.

$$I_R = \frac{E}{R}$$

$$I_R = \frac{120}{1000}$$

$$I_R = .12 \text{ amps}$$

$$I_L = \frac{E}{X_L}$$
$$I_L = \frac{120}{50}$$
$$I_L = 2.4 \text{ amps}$$

$$I_C = \frac{E}{X_C}$$
$$I_C = \frac{120}{25}$$
$$I_C = 4.8 \text{ amps}$$

Once the branch currents are known, total current can be calculated.

$$I_t = \sqrt{I_R{}^2 + (I_C - I_L)^2}$$
$$I_t = \sqrt{.12^2 + (4.8 - 2.4)^2}$$
$$I_t = \sqrt{.0144 + 5.76}$$
$$I_t = \sqrt{5.7744}$$
$$I_t = 2.4 \text{ amps}$$

Impedance is now found with an application of Ohm's Law.

$$Z_t = \frac{E_t}{I_t}$$
$$Z_t = \frac{120}{2.4}$$
$$Z_t = 50\ \Omega$$

Power and Power Factor in an AC Circuit

Power consumed by a resistor is dissipated in heat and not returned to the source. This is true power. True power is the rate at which energy is used. Current in an AC circuit rises to peak values and diminishes to zero many times a second. The energy stored in the magnetic field of an inductor, or plates of a capacitor, is returned to the source when current changes direction. Power in an AC circuit is the vector sum of true power and reactive power. This is called apparent power. True power is equal to apparent power in a purely resistive circuit because voltage and current are in phase. Voltage and current are also in phase in a circuit containing equal values of inductive reactance and capacitive reactance. If voltage and current are 90 degrees out of phase, as would be in a purely capacitive or purely inductive circuit, the average value of true power is equal to zero. There are high positive and negative peak values of power, but when added together the result is zero.

True power and apparent power formulas

The formula for apparent power is:

$$P = EI$$

Apparent power is measured in volt-amps (VA).

True power is calculated from another trigonometric function, the cosine of the phase angle ($\cos \theta$). The formula for true power is:

$$P = EI \cos \theta$$

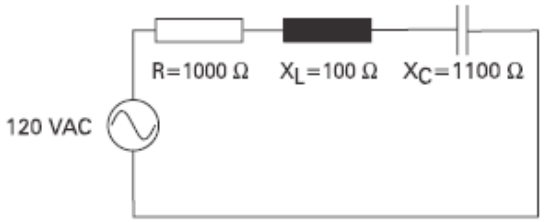
True power is measured in watts.

In a purely resistive circuit, current and voltage are in phase. There is a zero degree angle displacement between current and voltage. The cosine of zero is one. Multiplying a value by one does not change the value. In a purely resistive circuit the cosine of the angle is ignored.

In a purely reactive circuit, either inductive or capacitive, current and voltage are 90 degrees out of phase. The cosine of 90 is zero. Multiplying a value times zero results in a zero product. No power is consumed in a purely reactive circuit.

Calculating apparent power in a simple R-L-C circuit

In the following 120 volt circuit, I_t is equal to 84.9 milliamps. Inductive reactance is 100 Ω and capacitive reactance is 1100 Ω. The phase angle is -45 degrees. By referring to a trigonometric table, the cosine of -45 degrees is found to be .7071.



The apparent power consumed by the circuit is:

$$P = EI$$
$$P = 120 \times .0849$$
$$P = 10.2\ VA$$

The true power consumed by the circuit is:

$$P = EI\ \cos\ \theta$$
$$P = 120 \times .0849 \times .7071$$
$$P = 7.2\ watts$$

Another formula for true power is:

$$P = I^2R$$
$$P = .0849^2 \times 1000$$
$$P = 7.2\ watts$$

Power factor

Power factor is the ratio of true power to apparent power in an AC circuit. Power factor is expressed in the following formula:

$$PF = \frac{PT}{PA}$$

Power factor can also be expressed using the formulas for true power and apparent power. The value of *EI* cancels out because it is the same in the numerator and denominator. Power factor is the cosine of the angle.

$$PF = \frac{EI \cos \theta}{EI}$$
$$PF = \cos \theta$$

In a purely resistive circuit, where current and voltage are in phase, there is no angle of displacement between current and voltage. The cosine of a zero degree angle is one. The power factor is one. This means that all energy delivered by the source is consumed by the circuit and dissipated in the form of heat.

In a purely reactive circuit, voltage and current are 90 degrees apart. The cosine of a 90 degree angle is zero. The power factor is zero. This means the circuit returns all energy it receives from the source to the source.

In a circuit where reactance and resistance are equal, voltage and current are displaced by 45 degrees. The cosine of a 45 degree angle is .7071. The power factor is .7071. This means the circuit has used approximately 70% of the energy supplied by the source and returned approximately 30%.

Review 9

1. In a circuit containing inductance, capacitance, or both, opposition to current flow is called _____ .

2. Total opposition to current flow in a circuit that contains both reactance and resistance is called _____ .

3. In a 50 hertz circuit, containing a 10 mh inductor, the inductive reactance is _____ ohms.

4. In a purely inductive circuit,

   a. current and voltage are in phase
   b. current leads voltage by 90 degrees
   c. current lags voltage by 90 degrees

5. In a purely capacitive circuit,

   a. current and voltage are in phase
   b. current leads voltage by 90 degrees
   c. current lags voltage by 90 degrees

6. In a 50 hertz circuit, containing a 10 microfarad capacitor, the capacitive reactance is _____ ohms.

7. In a circuit with 5 Ω resistance, and 10 Ω inductive reactance, impedance is _____ ohms.

8. In a circuit with 5 Ω resistance, and 4 Ω capacitive reactance, impedance is _____ ohms.

Review 10

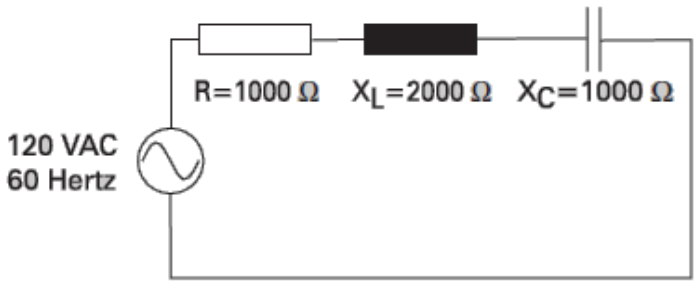
1. An AC circuit is _____ if inductive reactance and capacitive reactance are equal.

2. A series AC circuit is _____ if there is more inductive reactance than capacitive reactance.

3. A series AC circuit is _____ if there is more capacitive reactance than inductive reactance.

4. In a 120 VAC, 60 hertz series circuit, with 1000 Ω of resistance, 10 mh of inductance and 4 µF of capacitance, impedance is _____ Ω and current is _____ amps.

5. In the illustrated circuit,



I_t is _____ amps, and impedance is _____ Ω.

6. True power is measured in _____ .

7. A circuit with .2 amps flowing through 100 Ω of resistance, is consuming _____ watts.

SIEMENS STEP 2000 Self-Study Courses

WEEK 11

Notes

Notes

Notes

Notes

ELECTRICAL MACHINES – Home study

- Please, go to howstuffwork.com and search for How Electric Motors Work
- Search online the next two documents from the Department of Energy: h1011v2 and h1011v4. These are the volumes 2 and 4 of the DOE Fundamentals Handbook – Electrical Science. Beware of the websites that might be listed before the DOE website and sell this PUBLIC DOMAIN (totally free) material[1].

Based on How Electric Motors Work, h1011v2 Module 6 and h1011v4 Module 12 answer the next questions

DC MOTORS

1. List the basic six parts of a DC motor
   - _
   - _
   - _
   - _
   - _
   - _
2. Torque is _____
   a) The force which produce and maintain rotation
   b) The force which keeps the motor attached to ground
   c) The speed of the motor
3. The amount of Torque is inverse proportional to the field flux ϕ
   ☐ True
   ☐ False

[1] The whole manual can be downloaded as four PDF documents. To complete all the four volumes search and download h1011v1 (volume 1) and h1011v3 (volume 3)

4. The field flux increases if the field current decreases

- ☐ True
- ☐ False

5. What does CEMF stand for? _____

6. If the CEMF decreases the speed of the motor …

- ☐ Increases
- ☐ Decreases

7. Draw the three basic configurations of DC motors (series, parallel and compound)

Series Motor	Shunt (parallel) Motor	Compound Motor

8. Give a couple of examples to illustrate the use of Series and Shunt motors

- _
- _

AC MOTORS

1 List the basic two parts of a AC motor

- _
- _

2 A rotating magnetic field can be achieved by applying a three phase AC to three windings symmetrically spaced around a stator.

☐ True

☐ False

3 Arrange in logical order the next four paragraphs (Write next to each paragraph 1st, 2nd, 3rd, or 4th.)

☐ This induced current will produce a magnetic field, opposite in polarity of the stator field, around the conductors of the rotor, which will try to line up with the magnetic field of the stator.

☐ The rotating magnetic field cuts the bars of the rotor and induces a current in them due to generator action.

☐ When alternating current is applied to the stator windings of an AC induction motor, a rotating magnetic field is developed

☐ Since the stator field is rotating continuously, the rotor cannot line up with, or lock onto, the stator field and, therefore, must follow behind it.

4 *Slip* is

☐ The maximum amount of torque a motor can deliver.

☐ The percentage difference between the speed of the rotor and the speed of the rotating magnetic field.

☐ The maximum speed that a motor can reach.

5 *Starting Torque* is the value of torque at

- ☐ 100% slip
- ☐ 50% slip
- ☐ 10% slip

6 *Starting Torque* is _____ of the full-load torque

- ☐ 200 to 300%
- ☐ 110 to 125%
- ☐ 150 to 200%

7 AC motors are broadly divided into two groups:

- ☐ Series and Parallel
- ☐ Induction and Repulsion
- ☐ Induction and Synchronous

LAB - Transformers

1) Measure the resistance of both coils of the provided transformer. The highest will be side 1, and the lowest side 2.

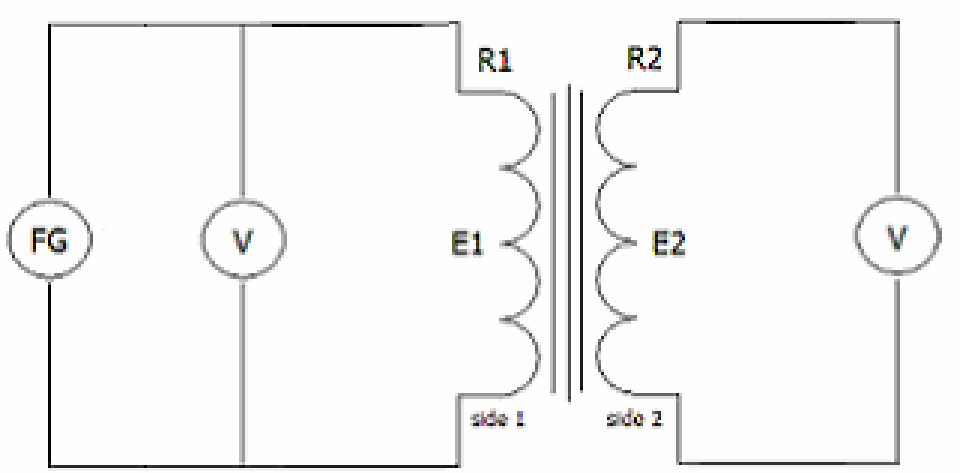
R side 1: _____

R side 2: _____

The resistance level of each coil will be proportional to the wire's gage and number of turns of each coil. R1 is the resistance of the coils with N1 windings, and R2 is the resistance of the coil with N2 windings. Since R1>R2 is reasonable to think that N1>N2.
It is not possible to know how many turn the coils have, but by applying a voltage to one coil and measuring the voltage induced in the other side it is possible to know their ratio since E1/E2 = N1/N2.

Build the next circuit, setting the FG as sine wave at 18 Vpp - 60 Hz and using two DMM as AC voltmeters.

These are measurements without load



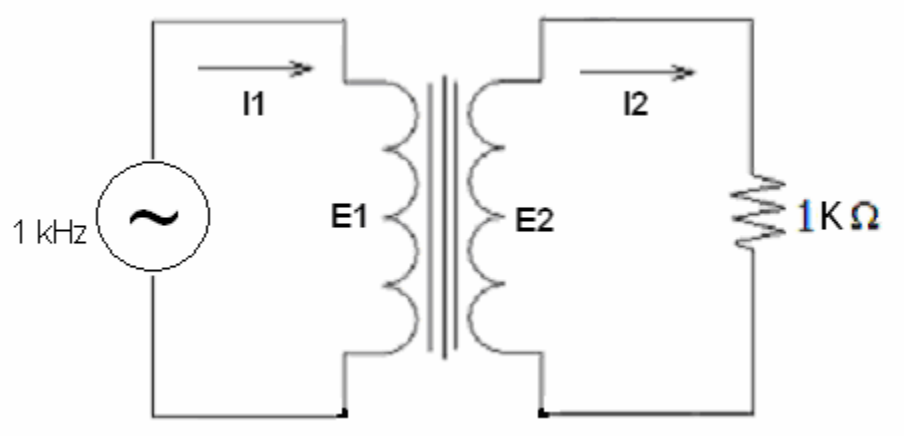
E1 =

E2 =

The E1/E2 ratio (XFMR ratio) is _____

Is it working as a step down or a step up? _____

2) Swap the terminals of the transformer in order to use the low resistance coil as the primary and the high resistance coil as the secondary.
Turn the Amplitude Control to maximum
Increase the frequency to 1 kHz.
Connect the resistor shown in the picture as a load



Is it working as a step down or a step up? _____

Measure using the bench DMM s

E1 =

E2 =

I1 =

I2 =

Read the V p-p in channels 1 and 2 (Set the channel used to measure V p-p2 and its probe in X10)

V p-p1=

V p-p2=

Verify the next equations

V p-p1 ÷ 2 = E1 x 1.41_____

V p-p2 ÷ 2 = E2 x 1.41_____

Calculate P1 and P2

P1 = E1 x I1 =

P2 = E2 x I2 =

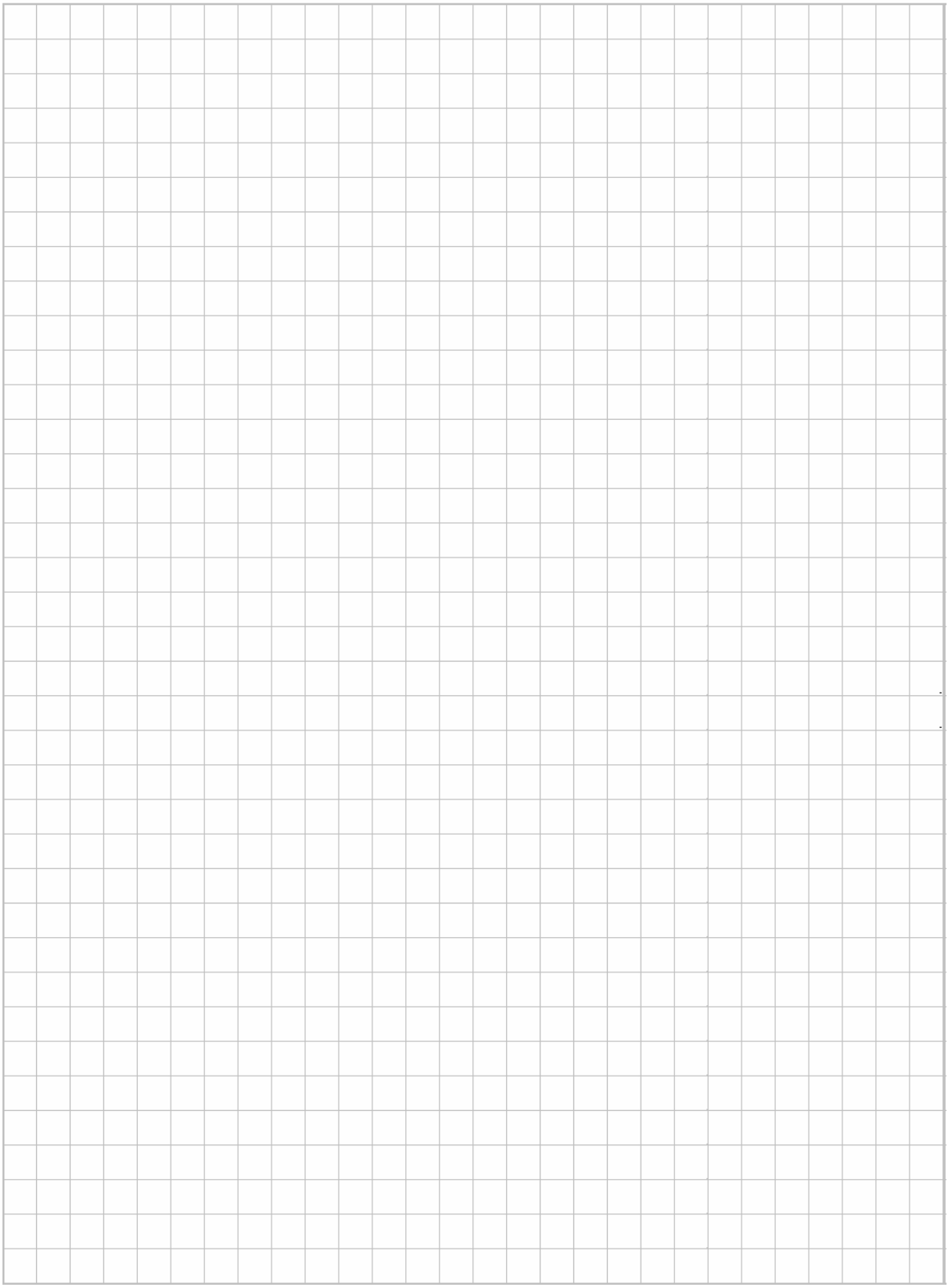
Calculate the efficiency of the transformer at 1kHz

Eff% = P2 ÷ P1 x 100 _____

~~~~~~

Maintenance tip – Identifying windings in unmarked transformers:

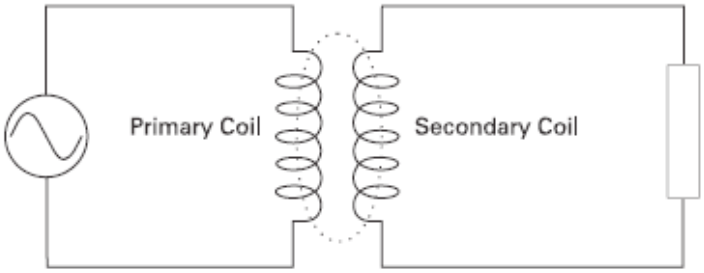
Remember, the resistance level is an indicative of the wire gage and number of turns in each transformer.
The size is indicative of the amount of power the unit can handle. Experience helps to recognize VA (Volts Amperes –unit of Power in AC) judging the volume of the unit.
~~~~~~



Transformers

Mutual induction

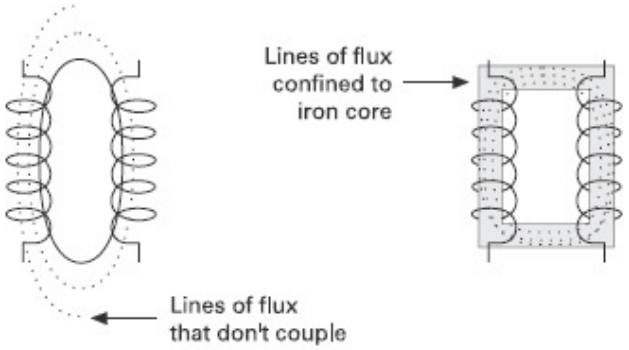
Transformers are electromagnetic devices that transfer electrical energy from one circuit to another by mutual induction. Mutual induction is the coupling of inductances by their mutual magnetic fields. In a single-phase transformer there are two coils, a primary and a secondary coil. The following circuit illustrates mutual induction. The AC generator provides electrical power to the primary coil. The magnetic field produced by the primary induces a voltage into the secondary coil, which supplies power to a load.



Transformers are used to step a voltage up to a higher level, or down to a lower level. Transformers are used extensively in power distribution systems, allowing power companies to transfer electrical energy many miles. Power generators typically generate high voltages. This voltage varies, depending on the generator, but a typical voltage might be 15 KV. The voltage is stepped up through a transformer to higher levels for transmission to substations. Typical voltages range from 115 KV to 765 KV. The electrical power is received at substation transformers many miles away where it is stepped down. Typical voltage might be 34 KV or 69 KV. From here, electrical power is fed to a distribution substation. It can also be fed directly to factory locations. If the power is fed to a factory, transformers at the factory site reduce the voltage to usable levels. The power fed to a distribution substation is reduced by transformers at the substation for factory and home use.

Coefficient of coupling

Mutual inductance between two coils depends on their flux linkage. Maximum coupling occurs when all the lines of flux from the primary coil cut through the secondary winding. The amount of coupling which takes place is referred to as coefficient of coupling. To maximize coefficient of coupling, both coils are often wound on an iron core which is used to provide a path for the lines of flux. The following discussion of step-up and step-down transformers applies to transformers with an iron core.



Voltage, current, and the number of turns in a coil

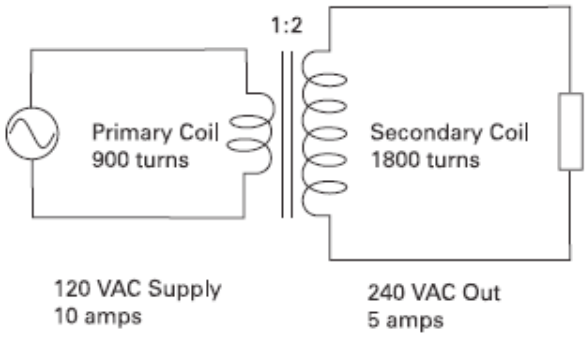
There is a direct relationship between voltage, impedance, current, and the number of coil turns in a transformer. This relationship can be used to find either primary or secondary voltage, current, and the number of turns in each coil. It is the number of turns which determine if a transformer is a step up or step down transformer. The following "rules-of-thumb" apply to transformers:

- If the primary coil has fewer turns than the secondary coil, it is a step-up transformer.
- If the primary coil has more turns than the secondary coil, it is a step-down transformer.

When the number of turns on the primary and seconday coils of a transformer are equal, input voltage, impedance, and current are equal to output voltage, impedance, and current.

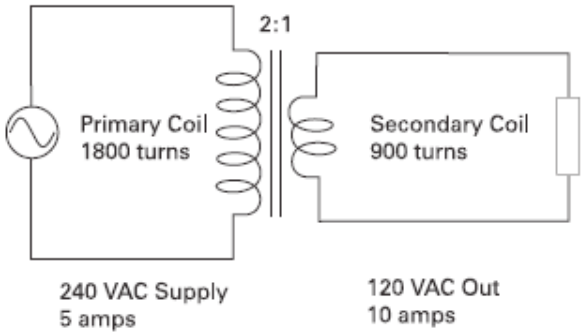
Step-up transformer

A step-up transformer is used when it is desirable to step voltage up in value. The following circuit illustrates a step-up transformer. The primary coil has fewer turns than the secondary coil. The number of turns in a transformer is given as a ratio. When the primary has fewer turns than the secondary, voltage and impedance are stepped up. In the circuit illustrated, voltage is stepped up from 120 VAC to 240 VAC. Because impedance is also stepped up, current is stepped down from 10 amps to 5 amps.



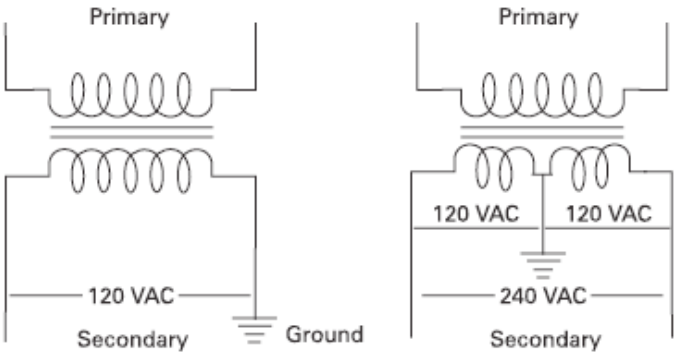
Step-down transformer

A step-down transformer is used when it is desirable to step voltage down in value. The following circuit illustrates a step-down transformer. The primary coil has more turns than the secondary coil. The step-down ratio is 2:1. Voltage and impedance are stepped down, current is stepped up.



Single-phase transformer connections

120 or 240 VAC single-phase transformers are used to supply lighting, receptacle, and small appliance loads. A transformer with a 240 VAC secondary can be used to supply 240 VAC to larger appliances such as stoves, air conditioners and heaters. A 240 VAC secondary can be tapped in the center to provide two sources of 120 VAC power.



Formulas for calculating the number of primary and secondary turns of a transformer

There are a number of useful formulas for calculating, voltage, current, and the number of turns between the primary and secondary of a transformer. These formulas can be used with either step-up or step-down transformers. The following legend applies to the transformer formulas:

E_S = secondary voltage
E_P = primary voltage
I_S = secondary current
I_P = primary current
N_S = turns in the secondary coil
N_P = turns in the primary coil

To find voltage:

$$E_S = \frac{E_P \times I_P}{I_S} \qquad E_P = \frac{E_S \times I_S}{I_P}$$

To find current:

$$I_S = \frac{E_P \times I_P}{E_S} \qquad I_P = \frac{E_S \times I_S}{E_P}$$

To find the number of coil turns:

$$N_S = \frac{E_S \times N_P}{E_P} \qquad N_P = \frac{E_P \times N_S}{E_S}$$

Using the values for the step-down transformer in the example of the previous page, the secondary voltage can be verified.

$$E_S = \frac{E_P \times I_P}{I_S}$$

$$E_S = \frac{240\ volts \times 5\ amps}{10\ amps}$$

$$E_S = \frac{1200}{10}$$

$$E_S = 120\ volts$$

Transformer ratings

Transformers are rated in kVA (kilovolt-amps). This rating is used rather than watts because loads are not purely resistive. Only resistive loads are measured in watts. The kVA rating determines the current a transformer can deliver to its load without overheating. Given volts and amps, kVA can be calculated. Given kVA and volts, amps can be calculated.

$$kVA = \frac{volts \times amps}{1000}$$

$$amps = \frac{kVA \times 1000}{volts}$$

Using the illustrated step-down transformer, the kVA rating can be calculated. The kVA rating of a transformer is the same for both the primary and the secondary.

$$Primary\ kVA = \frac{240 \times 5}{1000}$$

$$Primary\ kVA = 1.2\ kVA$$

$$Secondary\ kVA = \frac{120 \times 10}{1000}$$

$$Secondary\ kVA = 1.2\ kVA$$

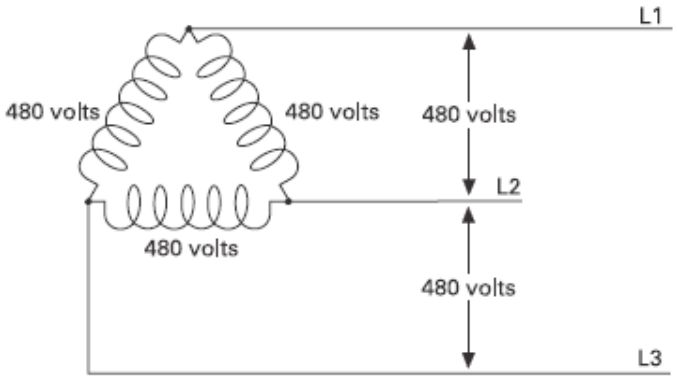
Transformer losses

Most of the electrical energy provided to the primary of a transformer is transferred to the secondary. Some energy, however, is lost in heat in the wiring or the core. Some losses in the core can be reduced by building the core of a number of flat sections called laminations.

Three-Phase Transformers

Delta connections

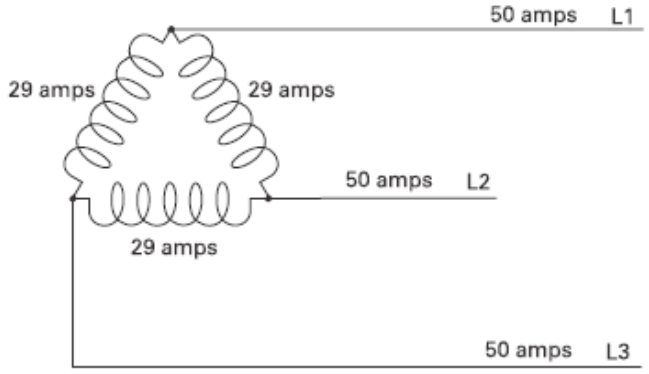
Three-phase transformers are used when three-phase power is required for larger loads such as industrial motors. There are two basic three-phase transformer connections, delta and wye. Delta transformers are used where the distance from the supply to the load is short. A delta is like three single-phase transformers connected together. The secondary of a delta transformer is illustrated below. For simplicity, only the secondary of a three-phase transformer is shown. The voltages shown on the illustration are secondary voltages available to the load. Delta transformers are schematically drawn in a triangle. The voltages across each winding of the delta triangle represents one phase of a three phase system. The voltage is always the same between any two wires. A single phase (L1 to L2) can be used to supply single phase loads. All three phases are used to supply three phase loads.



L1 to L2 = 480 volts
L2 to L3 = 480 volts
L1 to L3 = 480 volts

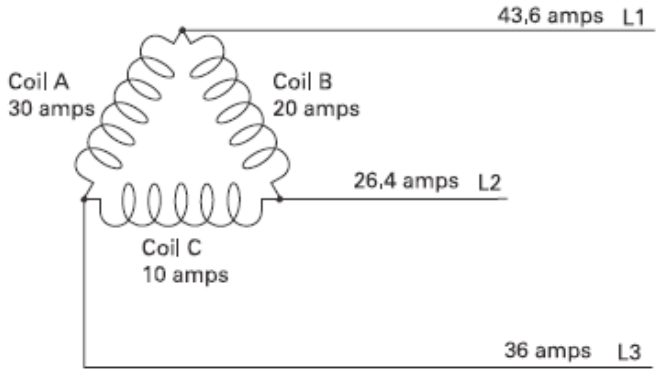
Balanced delta current

When current is the same in all three coils, it is said to be balanced. In each phase, current has two paths to follow. For example, current flowing from L1 to the connection point at the top of the delta can flow down through one coil to L2, and down through another coil to L3. When current is balanced, coil current is 58% of the line current measured on each phase. If the line current is 50 amps on each phase, coil current would be 29 amps.



Unbalanced delta current

When current is different in all three coils, it is unbalanced. The following diagram depicts an unbalanced system.



Though current is usually measured with an ammeter, line current of an unbalanced delta transformer can be calculated with the following formulas:

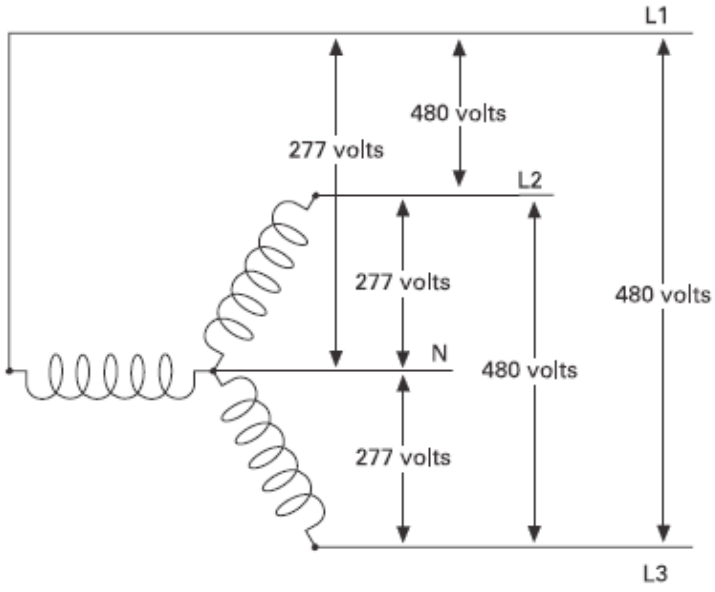
$$I_{L1} = \sqrt{I_A^2 + I_B^2 + (I_A \times I_B)}$$

$$I_{L2} = \sqrt{I_B^2 + I_C^2 + (I_B \times I_C)}$$

$$I_{L3} = \sqrt{I_A^2 + I_C^2 + (I_A \times I_C)}$$

Wye connections

The wye connection is also known as a star connection. Three transformers are connected to form a "Y" shape. The wye transformer secondary, (shown below) has four leads, three phase conductors, and one neutral. The voltage across any phase (line-to-neutral) will always be less than the line-to-line voltage. The line-to-line voltage is 1.732 times the line-to-neutral voltage. In the circuit below, line-to-neutral voltage is 277 volts. Line-to-line voltage will be 480 volts (277 x 1.732).



Review 11

1. If the primary of a transformer has more turns than the secondary, it is a _____ transformer.

2. If the primary of a transformer has fewer turns than the secondary, it is a _____ transformer.

3. The secondary voltage of an iron-core transformer with 240 volts on the primary, 40 amps on the primary, and 20 amps on the secondary is _____ volts.

4. A transformer with a 480 volt, 10 amp primary, and a 240 volt, 20 amp secondary will be rated for _____ kVA.

5. A wye connected, three-phase transformer secondary, with 240 volts line-to-line will have _____ volts line-to-neutral.

XFRMs – Questions & Problems

1) Why transformers cores are laminated?

_____

_____

_____

_____

2) What is the practical purpose of *step-up* transformers? – Give two examples

_____

_____

_____

_____

3) A single phase, 15kVA transformer has a 480V primary and a 240V secondary. What are the primary and the secondary current ratings of the transformer?

4) How many turns the secondary of a transformer has if the primary has 2400 turns, the primary voltage is 120V, and the secondary voltage is 18V?

5) A 7.5kVA transformer supplies a single phase circuit with its 120V secondary. What is the maximum current in that circuit?

WEEK 12

Notes

Notes

Notes

Notes

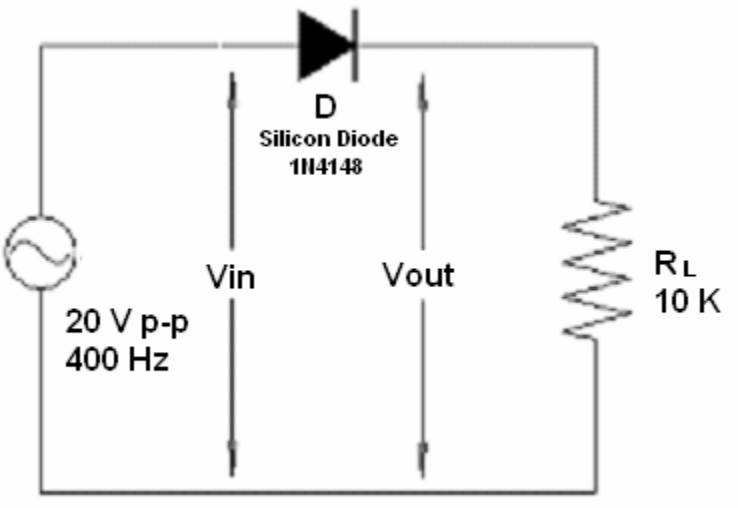
LAB – Diodes Rectifiers

1 Build in the next circuit the provided proto-board connecting the red lead of the FG to the diode's anode.

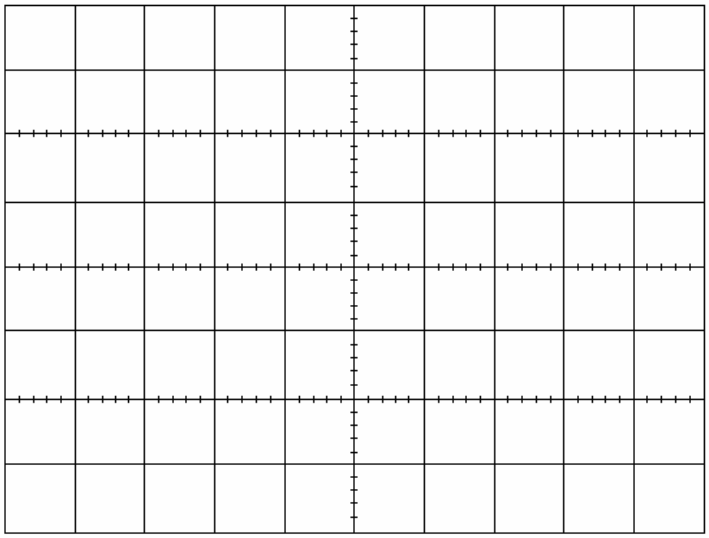
2 Set your oscilloscope in DC, and connected in a way that allows you to see Vi and Vo simultaneously.

3 Add in the circuit's diagram the connection of the oscilloscope and make a drawing of what it shows, **Mark the zero level for each channel**.

What kind of rectifier is this?_____.



Measure V out with your DMM (average voltage) and compare its reading with the oscilloscope's reading (peak). Set Coupling = DC

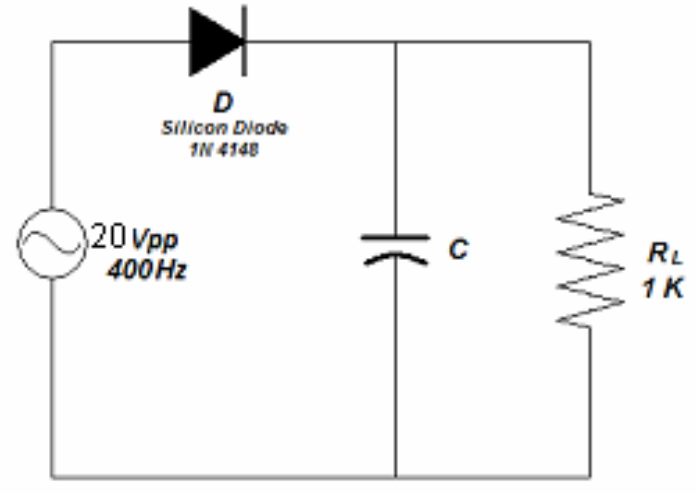


		V/Div	Time/Div
Setting	CH1	CH2	
* Measurement	V __	V __	T

* Next to "V" put "i" for input and "o" for output

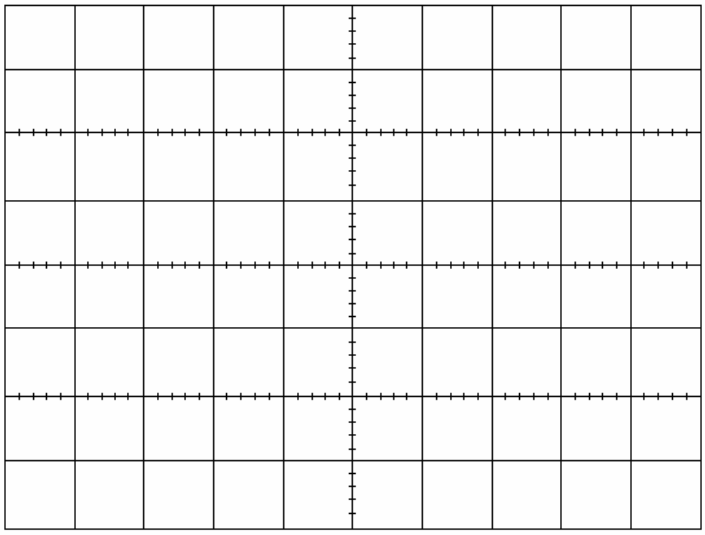
DMM Vo (average)	Scope Vo (peak)

Add to the former circuit a 1 µF electrolytic capacitor as shown in the next figure.



Use the oscilloscope to measure Vi and Vo and draw what the screen shows. **Mark the zero level for each channel.**

Measure Vo with your DMM and compare its reading with the oscilloscope's reading – Set Coupling = DC. Be careful indentifying from what line the Vo peak level should be measured [!]



	V/Div		Time/Div
Setting	CH1	CH2	
* Measurement	V ___	V ___	T

* Next to "V" put "i" for input and "o" for output

DMM Vo average	Scope Vo peak

Did V out increase with the introduction of C?

☐ Yes
☐ No

Measure the ripple peak-to-peak

Ripple peak-to-peak=

Repeat the last measurements but now replacing C by a 100µF unit.

DMM Vo (average)	Scope Vo (peak)

Ripple peak-to-peak=

Did the ripple decrease with the increase of the C?

- ☐ Yes
- ☐ No

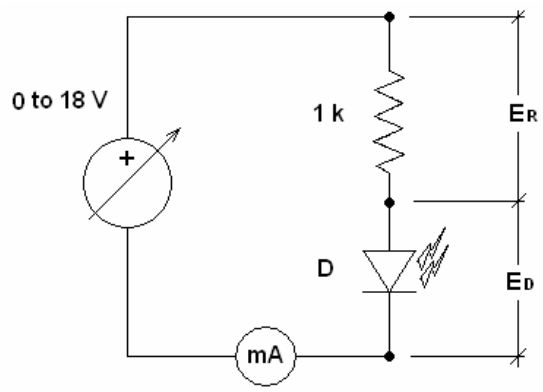
A 10% ripple is typical for non regulated power supplies
The capacitor can be calculated by

$$C = \frac{5 \times Io}{Vs \times f} \qquad \text{For } Io \simeq \frac{Vs}{Ro_{min}}$$

C = smoothing capacitance in farads (F)
Io = output current from the supply in amps (A)
Vs = supply voltage in volts (V), this is the peak value of the unsmoothed DC
Ro_{min} = Minimum expected load
f = frequency of the AC supply in hertz (Hz)

If using a Half-wave rectifier f = 60 Hz
If using a Full-wave rectifier f = 120 Hz

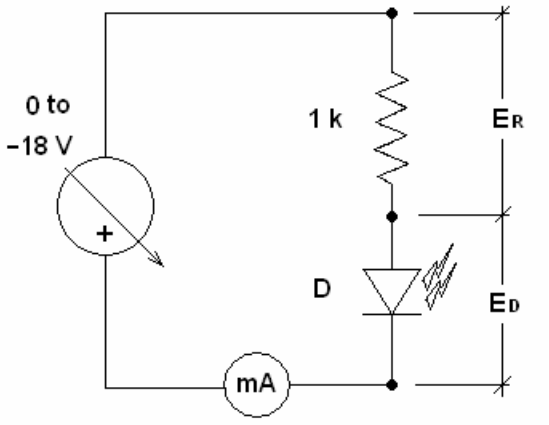
Build the next circuit and record ER, ED, and I for different levels of source voltage and complete the chart below.



E source	E_R	E_D	I
0 V	0 V	0 V	0 mA
1			
1.5			
2			
3			
5			
9			
14			
18			

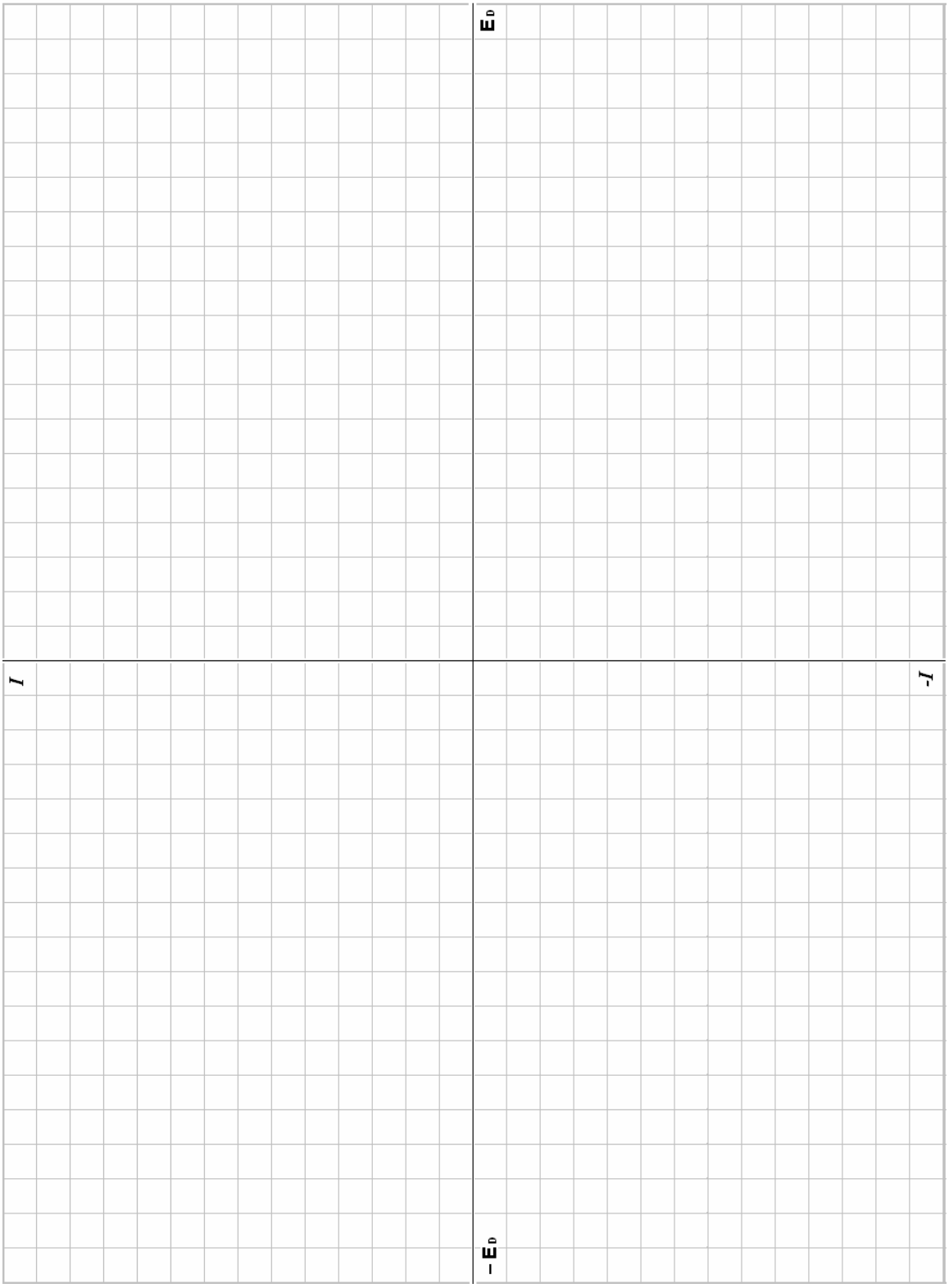
Based on the measurement in the chart plot two graphs: ED vs. E source and I vs. ED

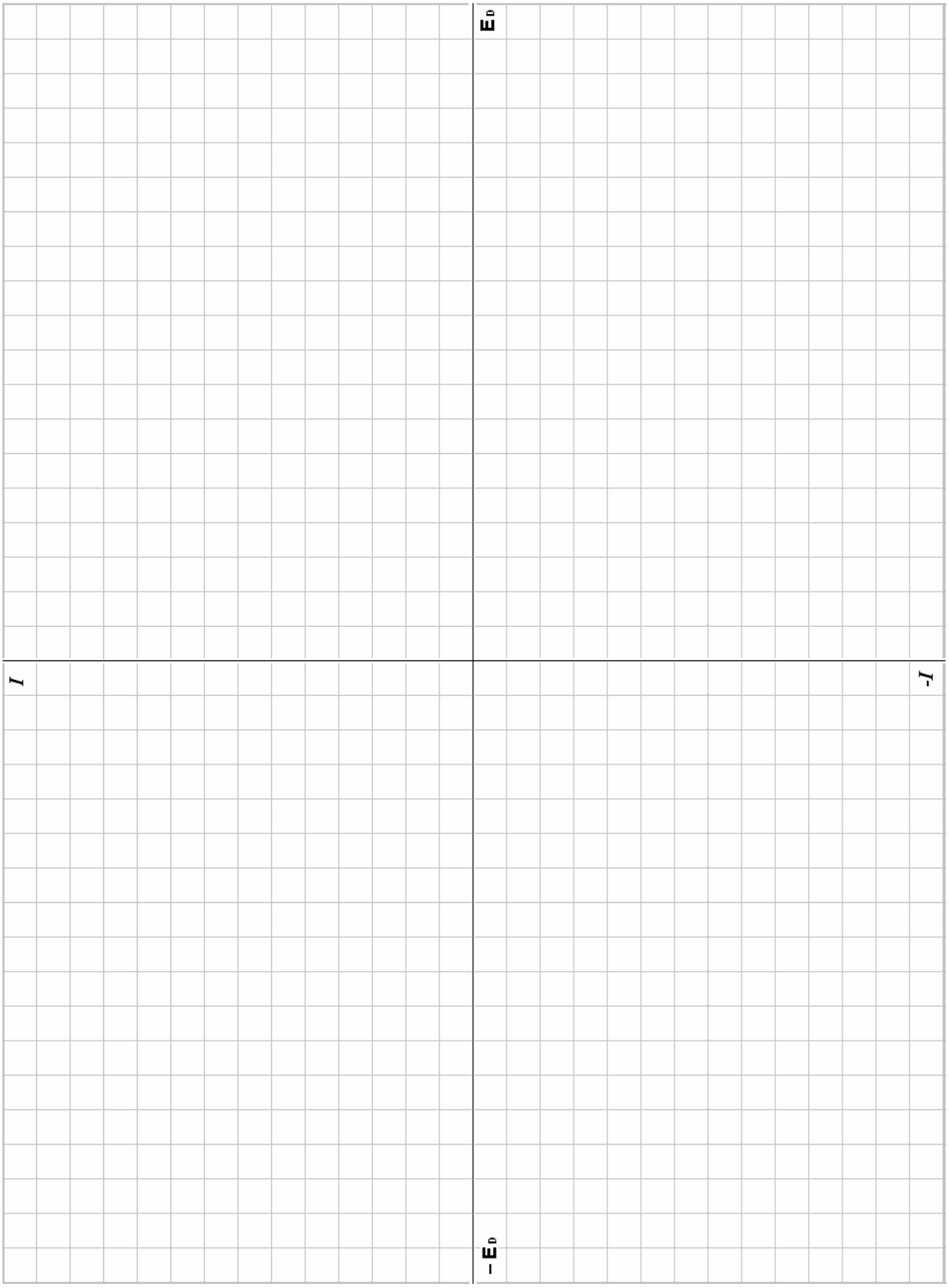
Swap the source terminals and repeat the experience



E source	E_R	E_D	I
0 V	0 V	0 V	0 mA
- 1			
- 1.5			
- 2			
- 3			
- 5			
- 9			
- 14			
- 18			

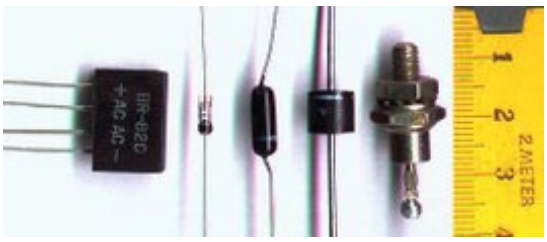
Based on the measurement in the chart plot two graphs: ED vs. E source and I vs. ED


E_D
I
$-I$
$-E_D$


E_D
I
$-I$
$-E_D$

Diode

From Wikipedia, the free encyclopedia



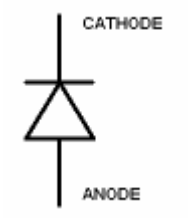
Types of diodes

In electronics, a **diode** is a component that restricts the direction of movement of charge carriers. It allows an electric current to flow in one direction, but essentially blocks it in the opposite direction. Thus the diode can be thought of as an electronic version of a check valve.

The first diodes were vacuum tube devices (called *valves* in the UK), but today the most common diodes are made from semiconductor materials such as silicon or germanium.

For much of the 20th century vacuum tube diodes were used in analog signal applications, and as rectifiers in power supplies. Tube diodes were nearly obsolete by 2001, except as rectifiers in tube guitar and hi-fi amplifiers and in a few specialized high-voltage applications.

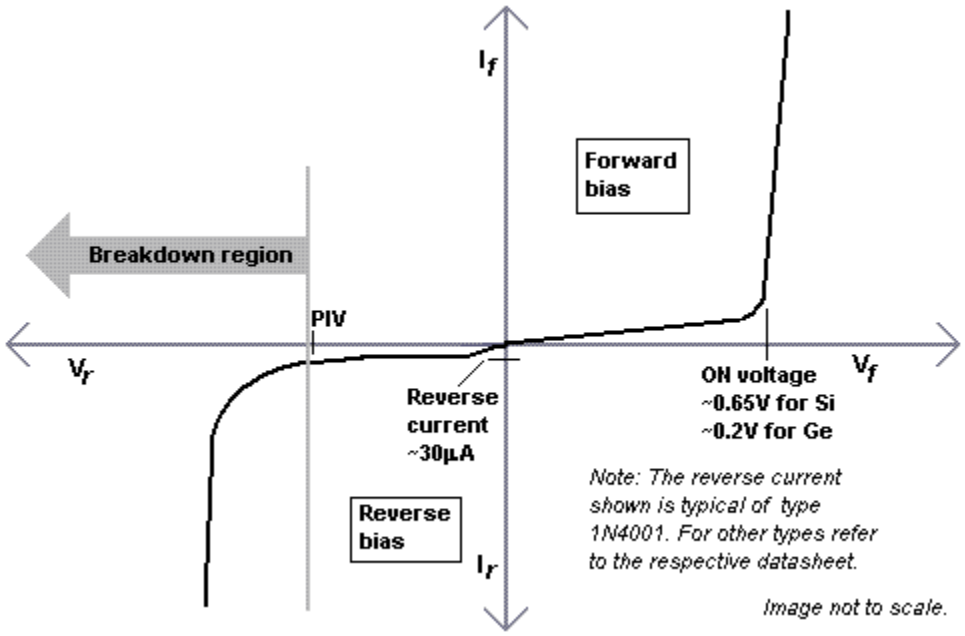
Semiconductor diodes



Most modern diodes are based on semiconductor p-n junctions. In a p-n diode, conventional current can flow from the p-type side (the anode) to the n-type side (the cathode), but not in the opposite direction. Another type of semiconductor diode, the Schottky diode, is formed from the contact between a metal and a semiconductor rather than by a p-n junction.

A semiconductor diode's current-voltage, or I-V, characteristic curve is ascribed to the behavior of the so-called **Depletion Layer** or Depletion Zone which exists at the p-n junction between the differing semiconductors. When a p-n junction is first created, conduction band (mobile) electrons from the N-doped region diffuse into the P-doped region where there is a large population of holes (places for electrons in which no electron is present) with which the electrons "recombine". When a mobile electron recombines with a hole, the hole vanishes and the electron is no longer mobile. Thus, two charges carriers have vanished. The region around the p-n junction becomes depleted of charge carriers and thus behaves as an insulator. However, the Depletion width cannot grow without limit. For each electron-hole pair that recombines, a positively-charged dopant ion is left behind in the N-doped region, and a

negatively charged dopant ion is left behind in the P-doped region. As recombination proceeds and more ions are created, an increasing electric field develops through the depletion zone which acts to slow and then finally stop recombination. At this point, there is a 'built-in' potential across the depletion zone. If an external voltage is placed across the diode with the same polarity as the built-in potential, the depletion zone continues to act as an insulator preventing a significant electric current. However, if the polarity of the external voltage opposes the built-in potential, recombination can once again proceed resulting in substantial electric current through the p-n junction. For silicon diodes, the built-in potential is approximately 0.6 V. Thus, if an external current is passed through the diode, about 0.6 V will be developed across the diode such that the P-doped region is positive with respect to the N-doped region and the diode is said to be 'turned on'.



I-V characteristics of a P-N junction diode (not to scale).

A diode's I-V, characteristic can be approximated by two regions of operation. Below a certain difference in potential between the two leads, the Depletion Layer has significant width, and the diode can be thought of as an open (non-conductive) circuit. As the potential difference is increased, at some stage the diode will become conductive and allow charges to flow, at which point it can be thought of as a connection with zero (or at least very low) resistance.

In the reverse bias region for a normal P-N rectifier diode, the current through the device is very low (in the µA range) for all reverse voltages upto a point called the peak-inverse-voltage (PIV). Beyond this point a process called reverse breakdown occurs which causes the device to be damaged along with a large increase in current. For special purpose diodes like the avalanche or zener diodes, the concept of PIV is not applicable since they have a deliberate breakdown beyond a known reverse current such that the reverse voltage is "clamped" to a known value (called zener voltage). The devices however have a maximum limit to the current and power in the zener or avalanche region.

Types of semiconductor diode

Diode	Light-Emitting Diode	Zener Diode	Schottky Diode

Some diode symbols

There are several types of semiconductor junction diodes:

Normal (p-n) diodes
which operate as described above. Usually made of doped silicon or, more rarely, germanium. Before the development of modern silicon power rectifier diodes, cuprous oxide and later selenium was used; its low efficiency gave it a much higher forward voltage drop (typically 1.4-1.7V per "cell," with multiple cells stacked to increase the peak inverse voltage rating in high voltage rectifiers), and required a large heat sink (often an extension of the diode's metal substrate), much larger than a silicon diode of the same current ratings would require.

'Gold doped' diodes
The gold causes 'minority carrier suppression.' This lowers the effective capacitance of the diode, allowing it to operate at signal frequencies. A typical example is the 1N914. Germanium and Schottky diodes are also fast like this, as are bipolar transistors 'degenerated' to act as diodes. Power supply diodes are made with the expectation of working at a maximum of 2.5 x 400 Hz (sometimes called 'French power' by Americans), and so are not useful above a kilohertz.

Zener diodes (pronounced /ziːnər/)
diodes that can be made to conduct backwards. This effect, called Zener breakdown, occurs at a precisely defined voltage, allowing the diode to be used as a precision voltage reference. In practical voltage reference circuits Zener and switching diodes are connected in series and opposite directions to balance the temperature coefficient to near zero. Some devices labeled as high-voltage Zener diodes are actually avalanche diodes (see below). Two (equivalent) Zeners in series and in reverse order, in the same package, constitute a transient absorber (or Transorb, a registered trademark). They are named for Dr. Clarence Melvin Zener of Southern Illinois University, inventor of the device.

Avalanche diodes
diodes that conduct in the reverse direction when the reverse bias voltage exceeds the breakdown voltage. These are electrically very similar to Zener diodes, and are often mistakenly called Zener diodes, but break down by a different mechanism, the Avalanche Effect. This occurs when the reverse electric field across the p-n junction causes a wave of ionization, reminiscent of an avalanche, leading to a large current. Avalanche diodes are designed to break down at a well-defined reverse voltage without being destroyed. The difference between the avalanche diode (which has a reverse breakdown above about 6.2 V) and the Zener is that the channel length of the former exceeds the 'mean free path' of the electrons, so there are collisions between them on the way out. The only practical difference is that the two types have temperature coefficients of opposite polarities.

Transient voltage suppression (TVS) diodes

These are avalanche diodes designed specifically to protect other semiconductor devices from electrostatic discharges. Their p-n junctions have a much larger cross-sectional area than those of a normal diode, allowing them to conduct large currents to ground without sustaining damage.

Photodiodes

these have wide, transparent junctions. Photons can push electrons over the junction, causing a current to flow. Photo diodes can be used as solar cells, and in photometry. If a photon doesn't have enough energy, it will not overcome the band gap, and will pass through the junction.

Light-emitting diodes (LEDs)

In a diode formed from an direct band-gap semiconductor, such as gallium arsenide, carriers that cross the junction emit photons when they recombine with the majority carrier on the other side. Depending on the material, wavelengths (or colors) from the infrared to the near ultraviolet may be produced. The forward potential of these diodes depends on the wavelength of the emitted photons: 1.2 V corresponds to red, 2.4 to violet. The first LED's were red and yellow, and higher-frequency diodes have been developed over time. All LEDs are monochromatic; 'white' LED's are actually combinations of three LED's of a different color, or a blue LED with a yellow scintillator coating. LED's can also be used as low-efficiency photodiodes in signal applications. An LED may be paired with a photodiode or phototransistor in the same package, to form an opto-isolator.

Laser diodes

When an LED-like structure is contained in a resonant cavity formed by polishing the parallel end faces, a laser can be formed. Laser diodes are commonly used in optical storage devices and for high speed optical communication.

Schottky diodes

have a lower forward voltage drop than a normal PN junction, because they are constructed from a metal to semiconductor contact. Their forward voltage drop at forward currents of about 1 mA is in the range 0.15V to 0.45 V, which makes them useful in voltage clamping applications and prevention of transistor saturation. They can also be used as low loss rectifiers although their reverse leakage current is generally much higher than non Schottky rectifiers. Schottky diodes are majority carrier devices and so do not suffer from minority carrier storage problems that slow down most normal diodes. They also tend to have much lower junction capacitance than PN diodes and this contributes towards their high switching speed and their suitability in high speed circuits and RF devices such as mixers and detectors.

Snap-off or 'step recovery' diodes

The term 'step recovery' relates to the form of the reverse recovery characteristic of these devices. After a forward current has been passing in an SRD and the current is interruped or reversed, the reverse conduction will cease very abruptly (as in a step waveform). SRDs can therefore provide very fast voltage transitions by the very sudden disappearance of the charge carriers.

Esaki or **tunnel diodes**

these have a region of operation showing negative resistance caused by quantum tunneling, thus allowing amplification of signals and very simple bistable circuits. These diodes are also the type most resistant to nuclear radiation.

Gunn diodes

these are similar to tunnel diodes in that they are made of materials such as GaAs or InP that exhibit a region of negative differential resistance. With appropriate biasing, dipole domains form and travel across the diode, allowing high frequency microwave oscillators to be built.

There are other types of diodes, which all share the basic function of allowing electrical current to flow in only one direction, but with different methods of construction.

Point Contact Diode

This works the same as the junction semiconductor diodes described above, but its construction is simpler. A block of n-type semiconductor is built, and a conducting sharp-point contact made with some group-3 metal is placed in contact with the semiconductor. Some metal migrates into the semiconductor to make a small region of p-type semiconductor near the contact. The long-popular 1N34 germanium version is still used in radio receivers as a detector and occasionally in specialized analog electronics.

Varicap or **varactor diodes**

These are used as voltage-controlled capacitors. These were important in PLL (phase-locked loop) and FLL (frequency-locked loop) circuits, allowing tuning circuits, such as those in television receivers, to lock quickly, replacing older designs that took a long time to warm up and lock. A PLL is faster than a FLL, but prone to integer harmonic locking (if one attempts to lock to a broadband signal). They also enabled tunable oscillators in early discrete tuning of radios, where a cheap and stable, but fixed-frequency, crystal oscillator provided the reference frequency for a voltage-controlled oscillator.

Current-limiting field-effect diodes

These are actually a JFET with the gate shorted to the source, and function like a two-terminal current-limiting analog to the Zener diode; they allow a current through them to rise to a certain value, and then level off at a specific value. Also called **CLDs**, **constant-current diodes**, or **current-regulating diodes**.

Other uses for semiconductor diodes include sensing temperature.

Applications

Radio demodulation

The first use for the diode was the demodulation of amplitude modulated (AM) radio broadcasts. In summary, an AM signal consists of alternating positive and negative peaks of voltage, whose amplitude or 'envelope' is proportional to the original audio signal, but whose average value is zero. The diode rectifies the AM signal (i.e. it eliminates peaks of one polarity), leaving a signal whose average amplitude is the desired audio signal. The average value is extracted using a simple filter and fed into an audio transducer (originally a crystal earpiece, now more likely to be a loudspeaker), which generates sound.

Power conversion

A **half wave rectifier** can be constructed from a single diode where it is used to convert alternating current electricity into direct current, by removing either the negative or positive portion of the AC input waveform.

A special arrangement of four diodes that will transform an alternating current into a direct current, using both positive and negative excursions of a single phase alternating current, is known as a diode bridge, single-phase bridge rectifier, or simply a **full wave rectifier**.

With a split (center-tapped) alternating current supply it is possible to obtain full wave rectification with only two diodes. Often diodes come in pairs, as **double diodes** in the same housing.

When it is desired to rectify three phase power, one could rectify each of the three phases with the arrangement of four diodes used in single phase, which would require a total of 12 diodes. However, due to redundancy, only six diodes are needed to make a three phase full wave rectifier. Most devices that generate alternating current (such devices are called **alternators**) generate three phase alternating current.

Disassembled automobile alternator, showing the six diodes that comprise a full-wave three phase bridge rectifier.

For example, an automobile alternator has six diodes inside it to function as a full wave rectifier for battery charge applications.

Over-voltage protection

Diodes are frequently used to conduct damaging high voltages away from sensitive electronic devices. They are usually reverse-biased (non-conducting) under normal circumstances, and become forward-biased (conducting) when the voltage rises above its normal value. For example, diodes are used in stepper motor and relay circuits to de-energize coils rapidly without the damaging voltage spikes that would otherwise occur. Many integrated circuits also incorporate diodes on the connection pins to prevent external voltages from damaging their sensitive transistors. Specialized diodes are used to protect from over-voltages at higher power (see Diode types above).

Logic gates

Diodes can be combined with other components to construct AND and OR logic gates.

Ionising radiation detectors

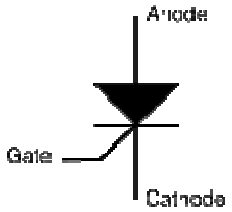
In addition to light, mentioned above, semiconductor diodes are sensitive to more energetic radiation. In electronics, cosmic rays and other sources of ionising radiation cause noise pulses and single and multiple bit errors. This effect is sometimes exploited by particle detectors to detect radiation. A single particle of radiation, with thousands or millions of electron volts of energy, generates many charge carrier pairs, as its energy is deposited in the semiconductor material. If the depletion layer is large enough to catch the whole shower or to stop a heavy particle, a fairly accurate measurement of the particle's energy can be made, simply by measuring the charge conducted and without the complexity of a magnetic spectrometer or etc. These semiconductor radiation detectors need efficient and uniform charge collection and low leakage current. They are often cooled by liquid nitrogen. For longer range (about a centimetre) particles they need a very large depletion depth and large area. For short range particles, they need any contact or un-depleted semiconductor on at least one surface to be very thin. The back-bias voltages are near breakdown (around a thousand volts per centimetre). Germanium and silicon are common materials. Some of these detectors sense position as well as energy. They have a finite life, especially when detecting heavy particle, because of radiation damage. Silicon and germanium are quite different in their ability to convert gamma rays to electron showers.

Semiconductor detectors for high energy particles are used in large numbers. Because of energy loss fluctuations, accurate measurement of the energy deposited is of less use.

Thyristor

From Wikipedia, the free encyclopedia

The **thyristor** is a solid-state semiconductor device with four layers of alternating N and P-type material. They act as a switch, conducting when their gate receives a current pulse, and continue to conduct for as long as they are forward biased (that is, as long as the voltage across the device has not reversed).



Circuit symbol for a thyristor

An SCR rated about 100 amperes, 1200 volts mounted on a heat sink - the two small wires are the gate trigger leads

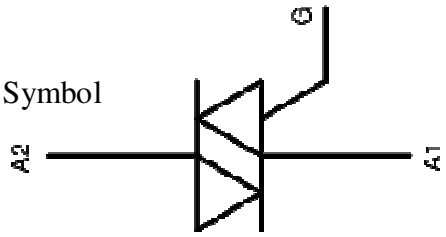
TRIAC

From Wikipedia, the free encyclopedia

A **TRIAC**, or **TRIode for Alternating Current** is an electronic component approximately equivalent to two silicon-controlled rectifiers (SCRs/thyristors) joined in inverse parallel (paralleled but with the polarity reversed) and with their gates connected together. Formal name for a TRIAC is **bidirectional triode thyristor**. This results in a bidirectional electronic switch which can conduct current in either direction when it is triggered (turned on). It can be triggered by either a positive or a negative voltage being applied to its *gate* electrode (with respect to A1, otherwise known as MT1). Once triggered, the device continues to conduct until the current through it drops below a certain threshold value, such as at the end of a half-cycle of alternating current (AC) mains power. This makes the TRIAC a very convenient switch for AC circuits, allowing the control of very large power flows with milliampere-scale control currents. In addition, applying a trigger pulse at a controllable point in an AC cycle allows one to control the percentage of current that flows through the TRIAC to the load (so-called *phase control*).

Low power TRIACs are used in many applications such as light dimmers, speed controls for electric fans and other electric motors, and in the modern computerized control circuits of many household small and major appliances. However, when used with inductive loads such as electric fans, care must be taken to assure that the TRIAC will turn off correctly at the end of each half-cycle of the ac power.

Triac Schematic Symbol

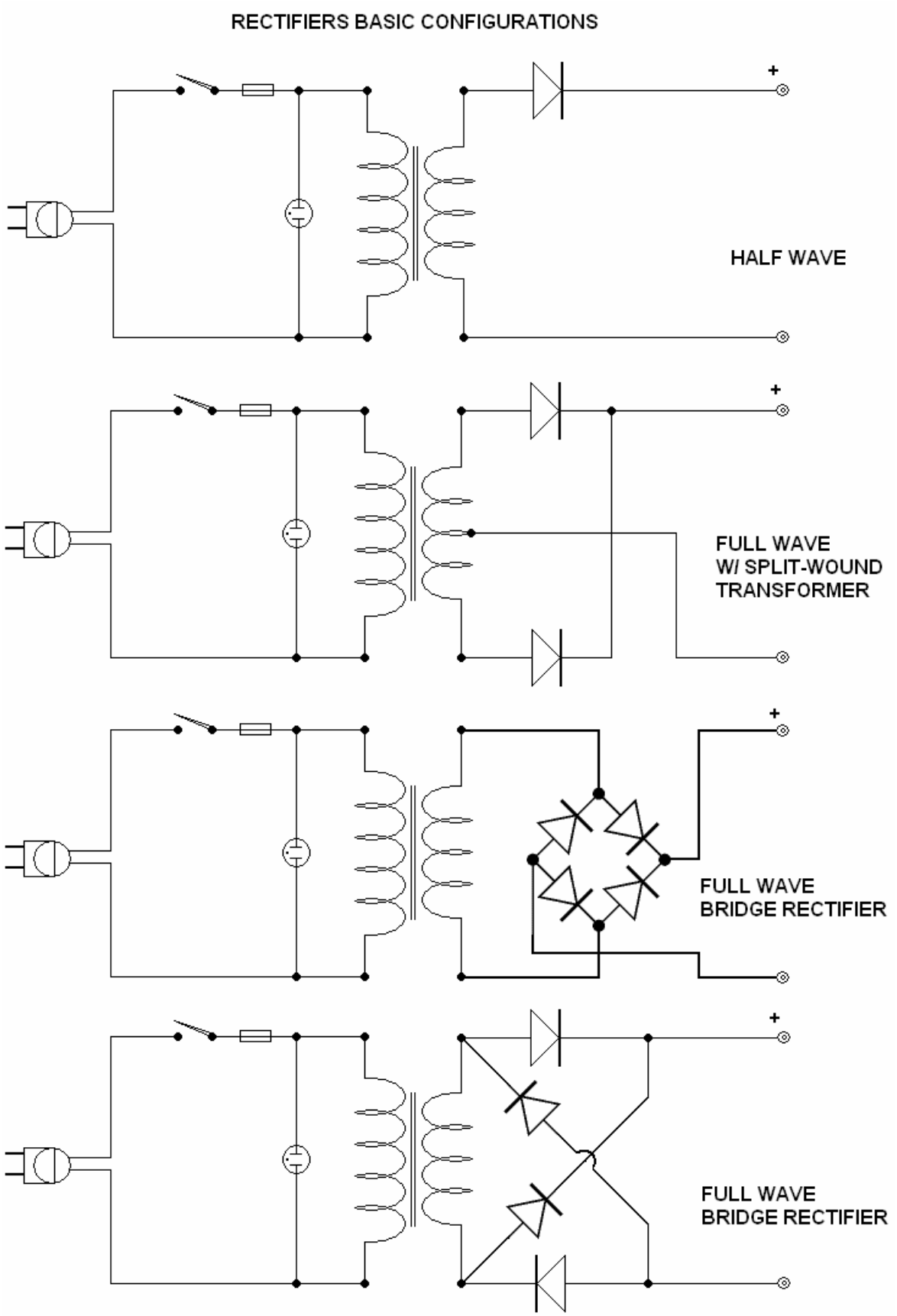


DIAC

From Wikipedia, the free encyclopedia

The **DIAC**, or **diode for alternating current**, is a bidirectional trigger diode that conducts current only after its breakdown voltage has been exceeded momentarily. When this occurs, the resistance of the diode abruptly decreases, leading to a sharp decrease in the voltage drop across the diode and, usually, a sharp increase in current flow through the diode. The diode remains "in conduction" until the current flow through it drops below a value characteristic for the device, called the holding current. Below this value, the diode switches back to its high-resistance (non-conducting) state. When used in AC applications this automatically happens when the current reverses polarity.

DIAC Schematic Symbol


RECTIFIERS BASIC CONFIGURATIONS
+
HALF WAVE
+
FULL WAVE
W/ SPLIT-WOUND
TRANSFORMER
+
FULL WAVE
BRIDGE RECTIFIER
+
FULL WAVE
BRIDGE RECTIFIER

.Diodes and Basic Power Supplies - Questions

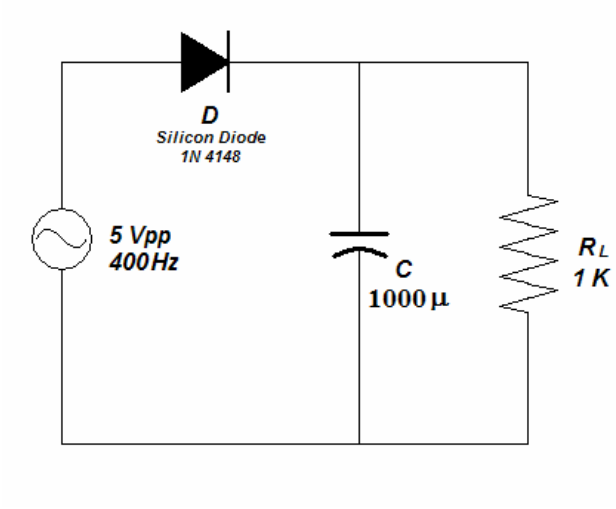
1 Draw a Half-wave and a Full-wave rectifier indicating input, output and output polarity.

Half-wave rectifier	Full-wave rectifier

2 Decreasing the capacitance of the capacitor used as output filter, the effective output voltage will __
   a. Increase
   b. Decrease

3 The output voltage of a rectifier with a capacitor as output filter, and **without** a load, is ____ than the output Vp of the rectifier without the capacitor.
   a. equal
   b. greater
   c. lower

4 What does happen to the output (DC level) in the next circuit when RL reduces its resistance? __



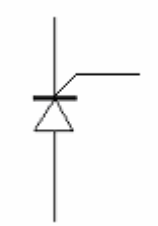
   a. Vo increases
   b. Vo decreases
   c. Vo

OVER PLEASE→

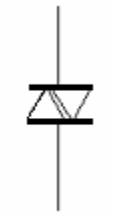
5 Match the next symbols with their acronyms

A

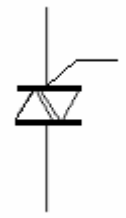
___ DIAC

B 

___ TRIAC

C 

___ LED

E 

___ SCR

WEEK 13

Week 13

Week 13

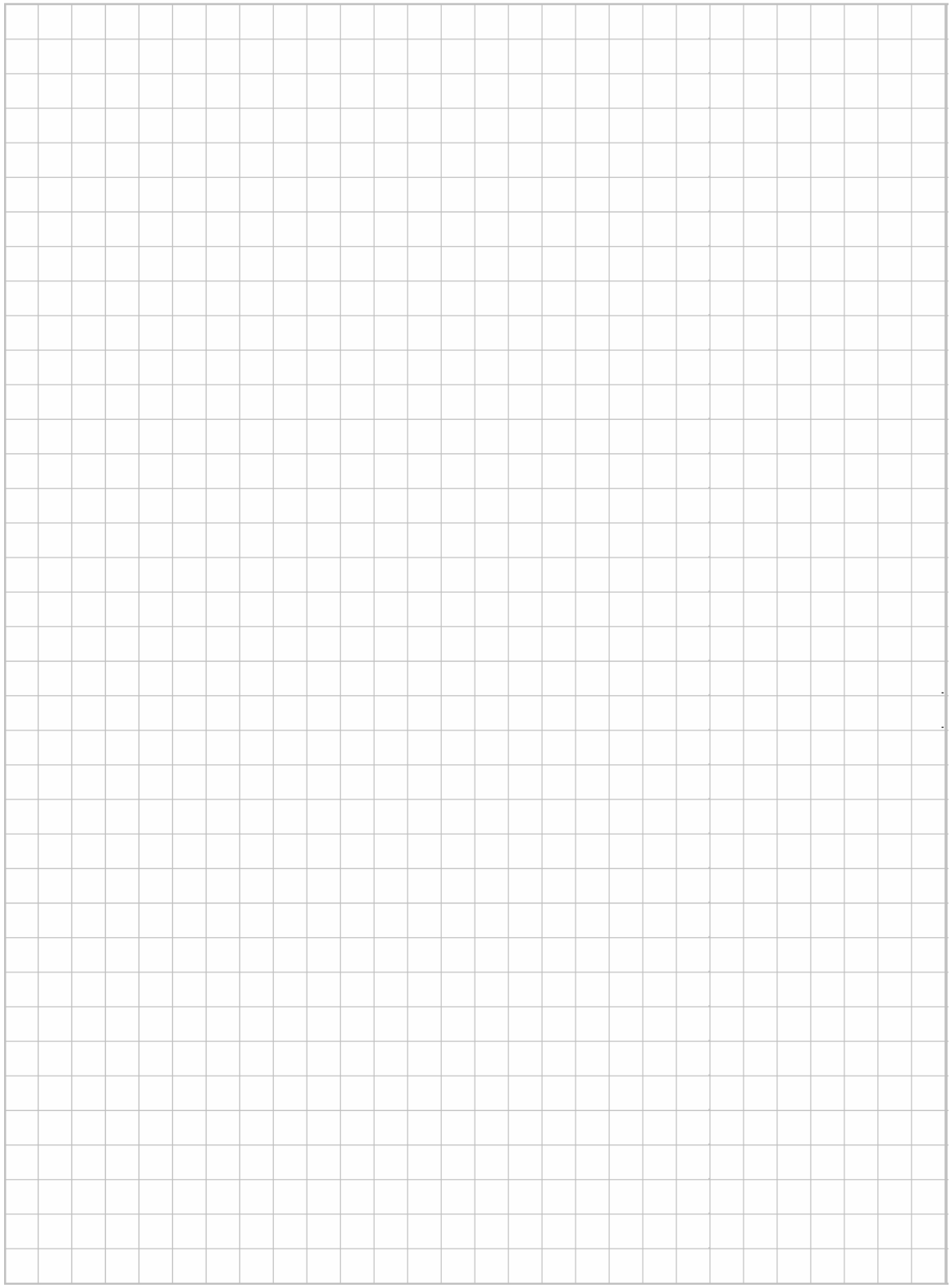
Notes

Week 13

Notes

Week 13

Notes



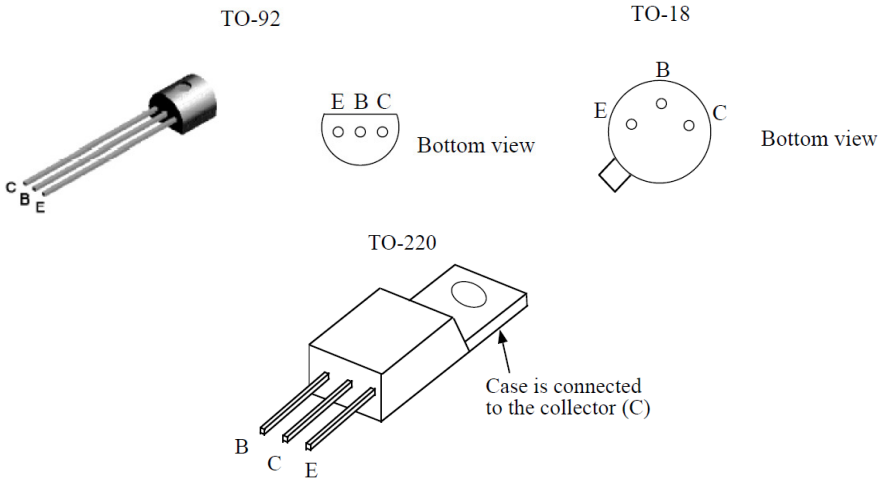
Week 13

Notes

Week 13 **Student name: _____**

Lab – Transistors

How recognize transistors terminals



What type of package is the unit to be used? _____

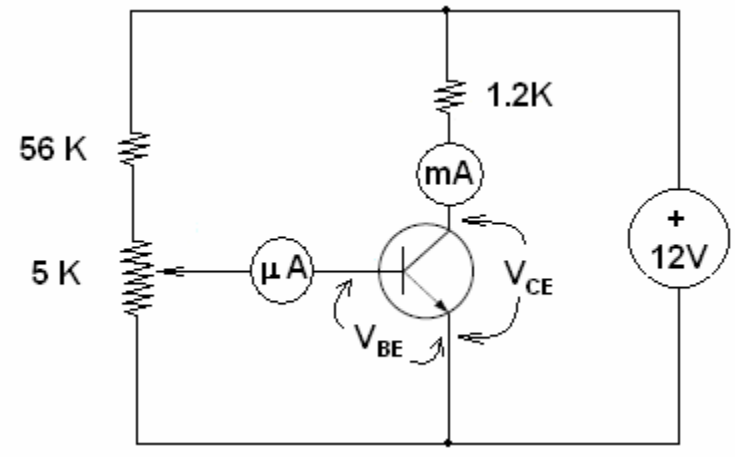
Using the hand-held DMM check if the unit is PNP or NPN and record its h_{FE}.

Type:

h_{FE}:

Build the next circuit and by incrementing I_B; record the variations on I_C.

Three instruments (DMM) are going to be needed. Use the bench DMM as a micro-ammeter, one hand-held DMM as milli-ammeter, and another as voltmeter to record V_{CE} and V_{BE}



Week 13 **Student name: _____**

I_B [µA]	I_C [mA]	$I_C \div I_B$	V_{BE} [V]	V_{CE} [V]
0				
1				
5				
10				
15				
25				
35				
50				
70				
100				

Results will be discussed in class

Build the next circuit

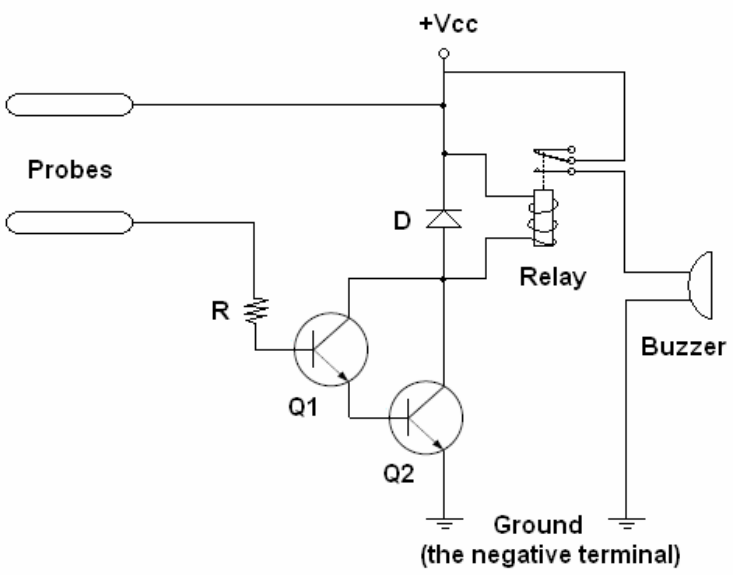
Put the probes 1 inch apart on top of a piece of cotton, fabric or paper.

Slowly drop water on the non conductive medium until Q1 and Q2 trigger the relay.

Take one probe off the humid medium

What was the result? _____

_____



Week 13 **Student name: _____**

What does the circuit do? _____

What is the purpose of D? _____

What is the name of the configuration Q1 and Q2 are connected? _____

What is the purpose of such configuration? _____

Week 13

From allaboutcircuits.com

Tony R. Kuphaldt

- **Date(s) of contribution(s):** 1996 to present
- **Nature of contribution:** Original author.

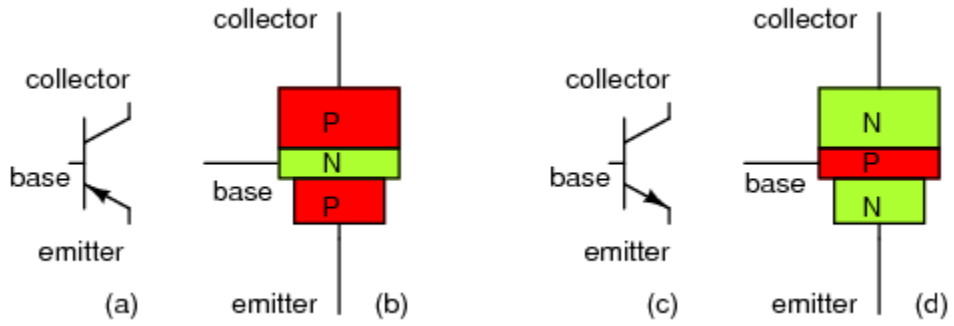
Edited by Adrian De Angelis for MELTEC/MINTEC 208

Introduction to Transistors

The invention of the bipolar transistor in 1948 ushered a revolution in electronics. Technical feats previously requiring relatively large, mechanically fragile, power-hungry vacuum tubes were suddenly achievable with tiny, mechanically rugged, power-thrifty specks of crystalline silicon. This revolution made possible the design and manufacture of lightweight, inexpensive electronic devices that we now take for granted. Understanding how transistors function is of paramount importance to anyone interested in understanding modern electronics.

My intent here is to focus as exclusively as possible on the practical function and application of bipolar transistors, rather than to explore the quantum world of semiconductor theory. Discussions of holes and electrons are better left to another chapter in my opinion. Here I want to explore how to *use* these components, not analyze their intimate internal details. I don't mean to downplay the importance of understanding semiconductor physics, but sometimes an intense focus on solid-state physics detracts from understanding these devices' functions on a component level. In taking this approach, however, I assume that the reader possesses a certain minimum knowledge of semiconductors: the difference between "P" and "N" doped semiconductors, the functional characteristics of a PN (diode) junction, and the meanings of the terms "reverse biased" and "forward biased."

A bipolar transistor consists of a three-layer "sandwich" of doped semiconductor materials, either P-N-P in Figure below (b) or N-P-N at (d). The schematic symbols are shown in Figure below (a) and (d).

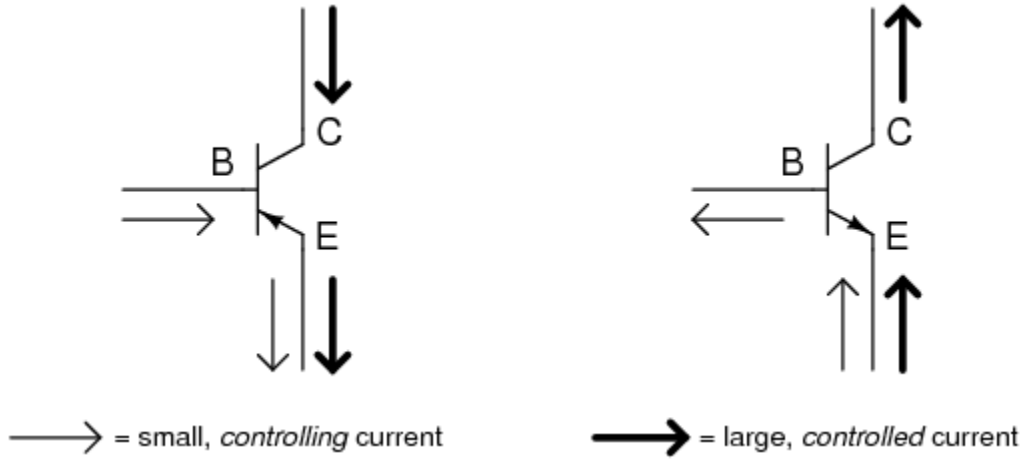


BJT transistor: (a) PNP schematic symbol, (b) physical layout (c) NPN symbol, (d) layout.

The functional difference between a PNP transistor and an NPN transistor is the proper biasing (polarity) of the junctions when operating. For any given state of operation, the current directions and voltage polarities for each kind of transistor are exactly opposite each other.

Week 13

Bipolar transistors work as current-controlled current *regulators*. In other words, transistors restrict the amount of current passed according to a smaller, controlling current. The main current that is *controlled* goes from collector to emitter, or from emitter to collector, depending on the type of transistor it is (PNP or NPN, respectively). The small current that *controls* the main current goes from base to emitter, or from emitter to base, once again depending on the kind of transistor it is (PNP or NPN, respectively). According to the standards of semiconductor symbology, the arrow always points *against* the direction of electron flow. (Figure below)



A small current base-emitter controls large collector-emitter current.

As you can see, the *controlling* current and the *controlled* current always merge together through the emitter wire. This is the first and foremost rule in the use of transistors: all currents must be going in the proper directions for the device to work as a current regulator.

The small, controlling current is usually referred to simply as the *base current* because it is the only current that goes through the base wire of the transistor. Conversely, the large, controlled current is referred to as the *collector current* because it is the only current that goes through the collector wire.

The emitter current is the sum of the base and collector currents, in compliance with Kirchoff's Current Law.

If there is not current flowing through the base , then the transistor shuts off like an open switch and prevents current through the collector.

A base current, turns the transistor on like a closed switch and allows a proportional amount of current through the collector.

Collector current is primarily limited by the base current, regardless of the amount of voltage available to push it.

Week 13

REVIEW:

Bipolar transistors consist of either a P-N-P or an N-P-N semiconductor "sandwich" structure.

The three leads of a bipolar transistor are called the *Emitter*, *Base*, and *Collector*.

Transistors function as current regulators by allowing a small current to *control* a larger current. The amount of current allowed between collector and emitter is primarily determined by the amount of current moving between base and emitter.

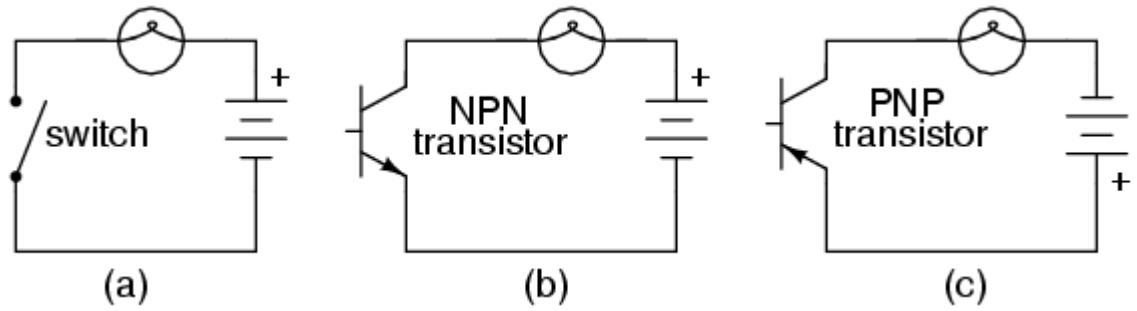
In order for a transistor to properly function as a current regulator, the controlling (base) current and the controlled (collector) currents must be going in the proper directions: meshing additively at the emitter. The real electron-flow goes *against* the emitter arrow symbol.

Transistors as Switches

Because a transistor's collector current is proportionally limited by its base current, it can be used as a sort of current-controlled switch. A relatively small flow of electrons sent through the base of the transistor has the ability to exert control over a much larger flow of electrons through the collector.

Suppose we had a lamp that we wanted to turn on and off with a switch. Such a circuit would be extremely simple as in Figure below (a).

For the sake of illustration, let's insert a transistor in place of the switch to show how it can control the flow of electrons through the lamp. Remember that the controlled current through a transistor must go between collector and emitter. Since it is the current through the lamp that we want to control, we must position the collector and emitter of our transistor where the two contacts of the switch were. We must also make sure that the lamp's current will move *against* the direction of the emitter arrow symbol to ensure that the transistor's junction bias will be correct as in Figure below (b).

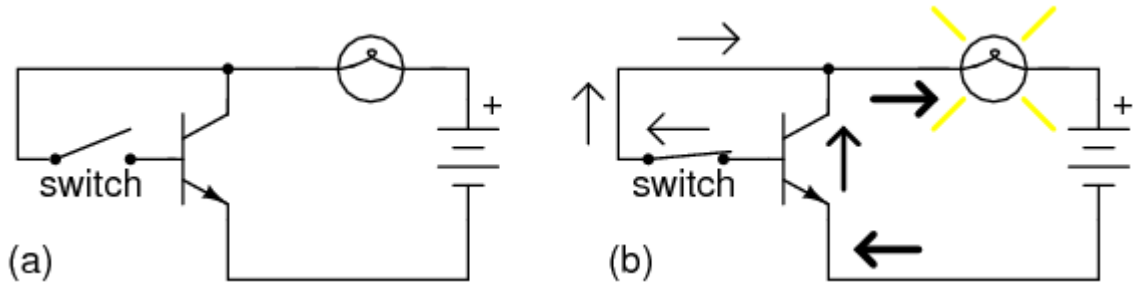


(a) Mechanical switch, (b) NPN transistor switch, (c) PNP transistor switch.

A PNP transistor could also have been chosen for the job. Its application is shown in Figure above (c).

The choice between NPN and PNP is really arbitrary. All that matters is that the proper current directions are maintained for the sake of correct junction biasing (electron flow going *against* the transistor symbol's arrow).

Going back to the NPN transistor in our example circuit, we are faced with the need to add something more so that we can have base current. Without a connection to the base wire of the transistor, base current will be zero, and the transistor cannot turn on, resulting in a lamp that is always off. Remember that for an NPN transistor, base current must consist of electrons flowing from emitter to base (against the emitter arrow symbol, just like the lamp current). Perhaps the simplest thing to do would be to connect a switch between the base and collector wires of the transistor as in Figure below (a).



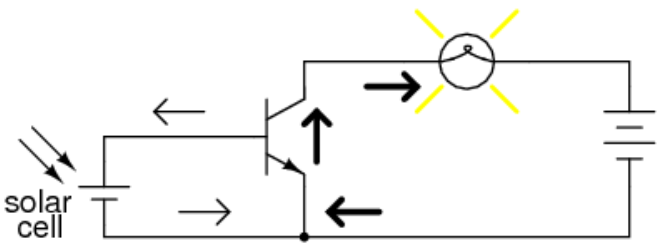
Transistor: (a) cutoff, lamp off; (b) saturated, lamp on.

If the switch is open as in (Figure above (a), the base wire of the transistor will be left "floating" (not connected to anything) and there will be no current through it. In this state, the transistor is said to be *cutoff*. If the switch is closed as in (Figure above (b), however, electrons will be able to flow from the emitter through to the base of the transistor, through the switch and up to the left side of the lamp, back to the positive side of the battery. This base current will enable a much larger flow of electrons from the emitter through to the collector, thus lighting up the lamp. In this state of maximum circuit current, the transistor is said to be *saturated*.

Of course, it may seem pointless to use a transistor in this capacity to control the lamp. After all, we're still using a switch in the circuit, aren't we? If we're still using a switch to control the lamp -- if only indirectly -- then what's the point of having a transistor to control the current? Why not just go back to our original circuit and use the switch directly to control the lamp current?

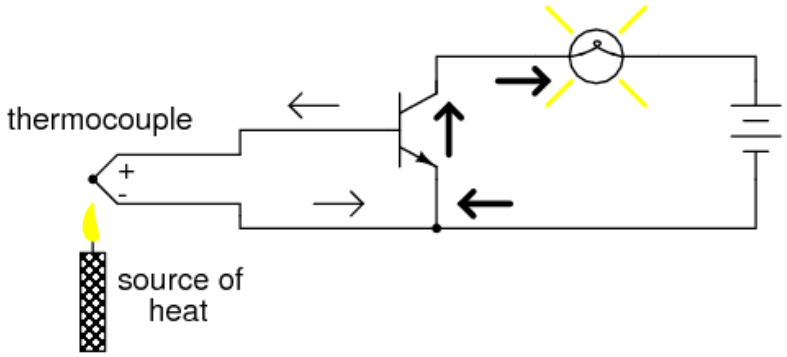
Two points can be made here, actually. First is the fact that when used in this manner, the switch contacts need only handle what little base current is necessary to turn the transistor on; the transistor itself handles most of the lamp's current.

This may be an important advantage if the switch has a low current rating: a small switch may be used to control a relatively high-current load. More important, the current-controlling behavior of the transistor enables us to use something completely different to turn the lamp on or off. Consider Figure below, where a pair of solar cells provides 1 V to overcome the 0.7 V_{BE} of the transistor to cause base current flow, which in turn controls the lamp.



Solar cell serves as light sensor.

Or, we could use a thermocouple (many connected in series) to provide the necessary base current to turn the transistor on in Figure below.



A single thermocouple provides 10s of mV. Many in series could produce in excess of the 0.7 V transistor V_{BE} to cause base current flow and consequent collector current to the lamp.

The point should be quite apparent by now: *any* sufficient source of DC current may be used to turn the transistor on, and that source of current only need be a fraction of the current needed to energize the lamp.

Here we see the transistor functioning not only as a switch, but as a true *amplifier*: using a relatively low-power signal to *control* a relatively large amount of power. Please note that the actual power for lighting up the lamp comes from the battery to the right of the schematic. It is not as though the small signal current from the solar cell, or thermocouple is being magically transformed into a greater amount of power. Rather, those small power sources are simply *controlling* the battery's power to light up the lamp.

REVIEW:

Transistors may be used as switching elements to control DC power to a load. The switched (controlled) current goes between emitter and collector; the controlling current goes between emitter and base.

When a transistor has zero current through it, it is said to be in a state of *cutoff* (fully non-conducting).

When a transistor has maximum current through it, it is said to be in a state of *saturation* (fully conducting).

Week 13

WEEK 14

WEEK 14

WEEK 14

Notes

WEEK 14

Notes

Integrated circuits

From Wikipedia, the free encyclopedia

In electronics, an **integrated circuit** (also known as **IC**, **microcircuit**, **microchip**, **silicon chip**, or **chip**) is a miniaturized electronic circuit (consisting mainly of semiconductor devices, as well as passive components) that has been manufactured in the surface of a thin substrate of semiconductor material. Integrated circuits are used in almost all electronic equipment in use today and have revolutionized the world of electronics.

A hybrid integrated circuit is a miniaturized electronic circuit constructed of individual semiconductor devices, as well as passive components, bonded to a substrate or circuit board.

Some useful ICs for small and educational projects

Voltage Regulators: Used to build simple DC regulated power supplies
- Fixed **LM7805** (positive regulator) and **LM7905** (negative regulator)
- Adjustable **LM317** (positive regulator) and **LM337** (negative regulator)

Op-Amps: Used for many applications such amplifiers, oscillators, analog calculators
- **LM741**
- **LM148** (quad 741)

Timers: Used to build timers or oscillators
- **LM555** or **NE555**
- **NE556** (dual 555)

Logical Gates
- **74LS00** (NAND)
- **74LS02** (NOR)

Counters SN7490 & **Decoders 74LS48**

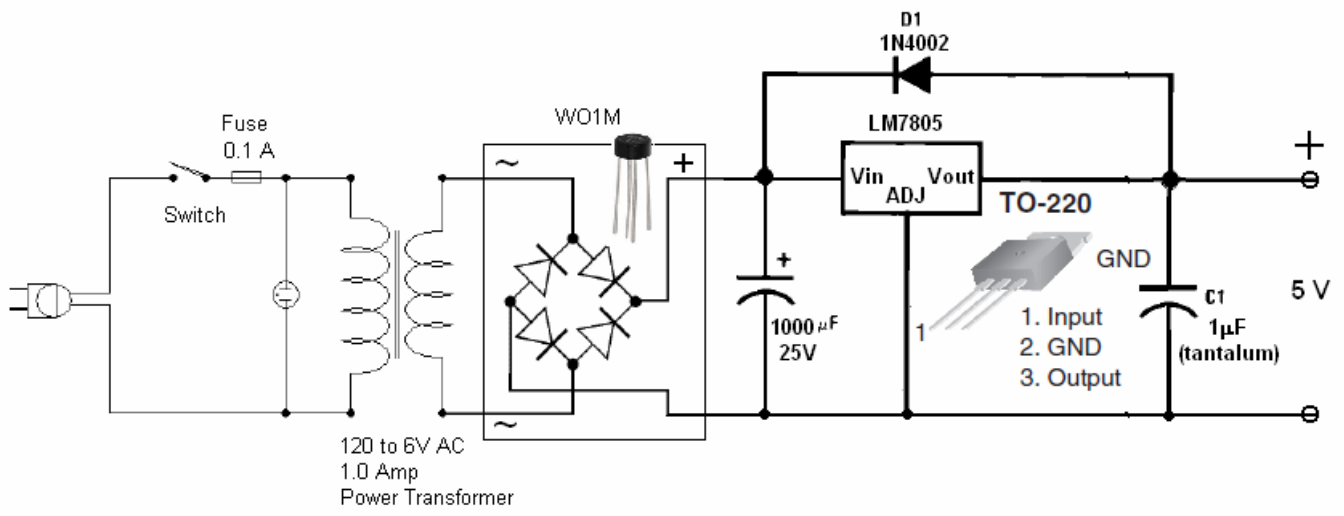
Optocouplers
- **4N25**
- **MCT9001** (dual optocoupler)

All these listed ICs have well developed technical papers available for free in the Internet. Four key terms to use when searching information on these (and others) ICs are: ***Data sheet***, ***AN*** (for application notes,) ***Tutorials***, and ***Projects***.

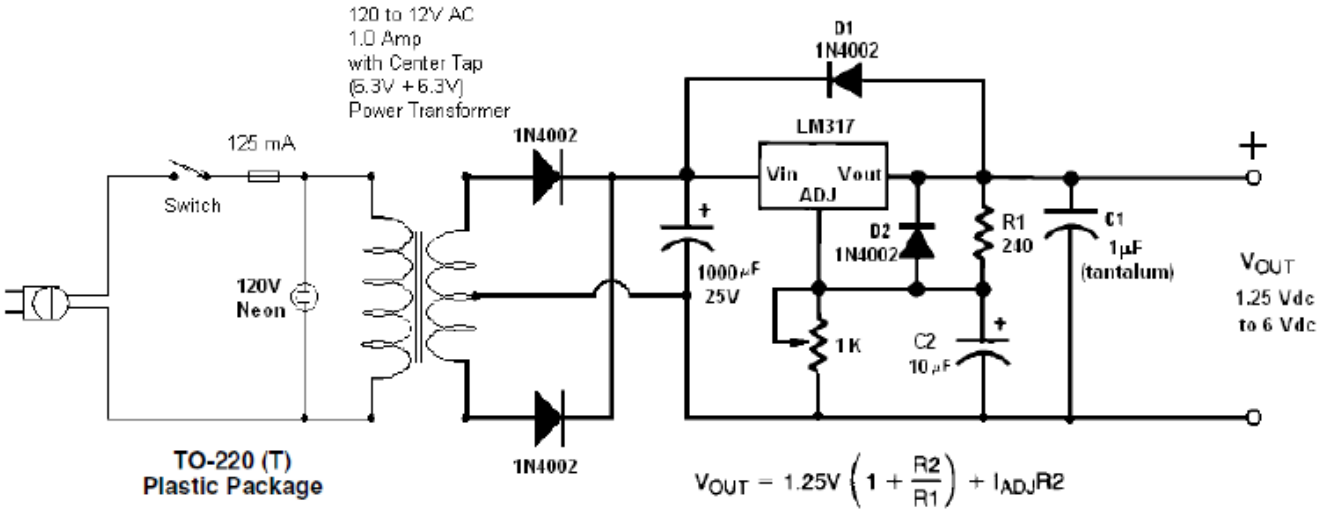
WEEK 14

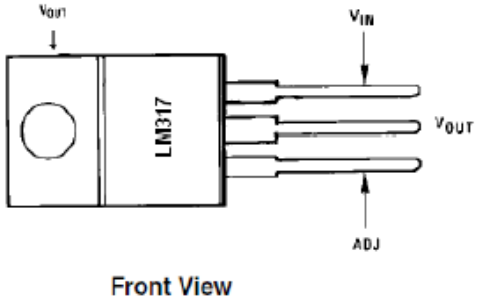
Example of applications: Next, some common circuits to illustrate the application of some of the IC listed above.

LM7805
Simple 5V 1Amp DC power supply



LM317
Simple 1.25V to 6V

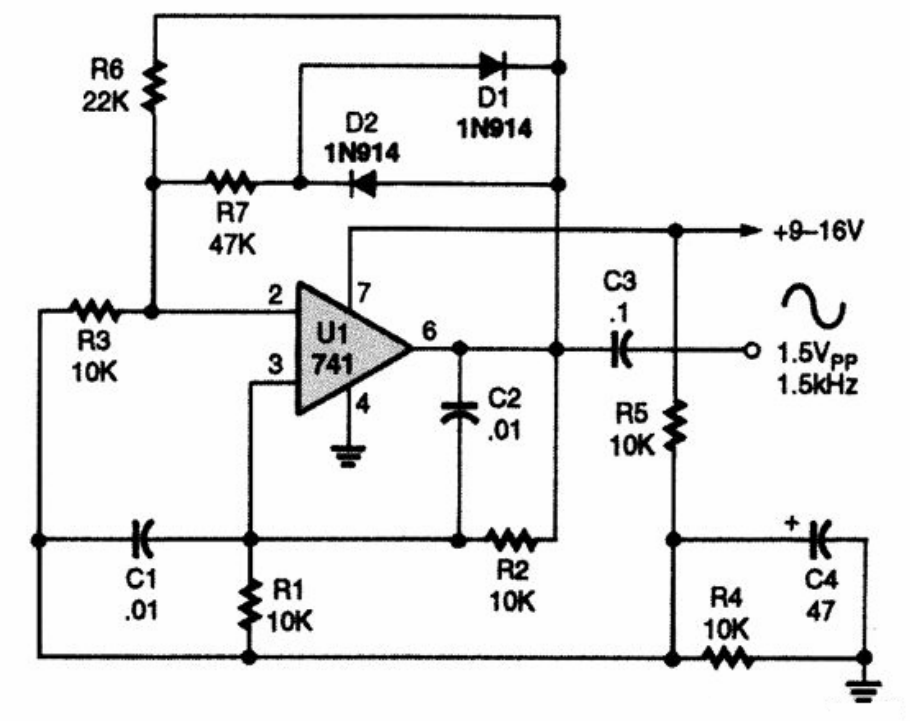




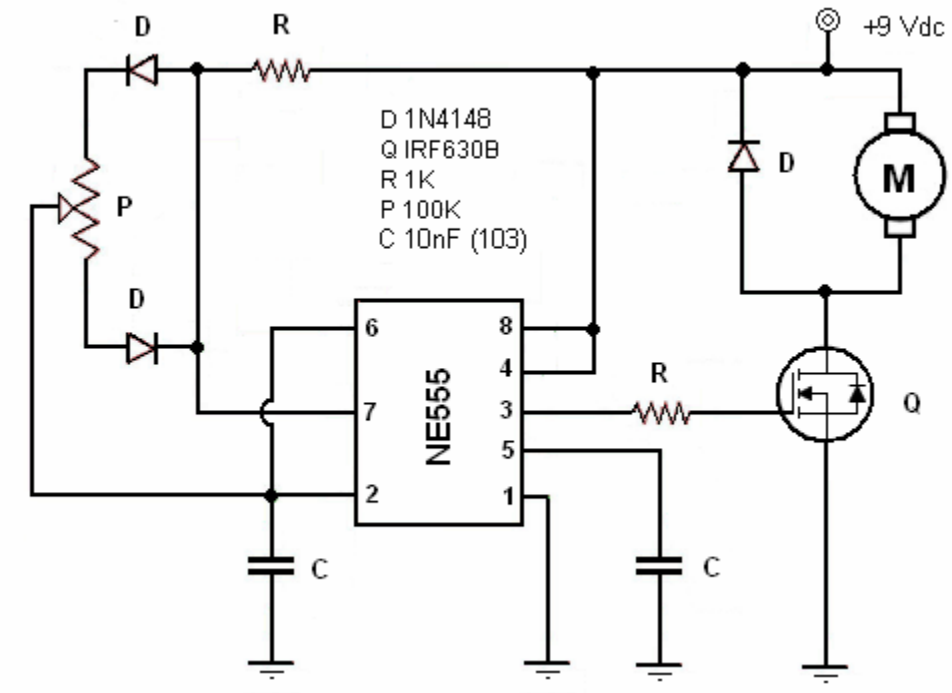
Front View

WEEK 14

LM741
1500 Hz Sine wave oscillator

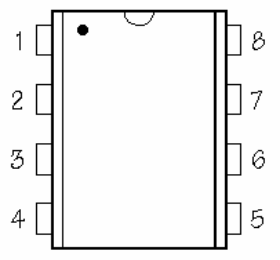


NE555
PWM Control



WEEK 14

How to identify the pin-out of a DIP (Dual In-line Package) IC



IC Dual In-line Package pin-out

Lab – ICs

Build the 555 based PWM

Using the oscilloscope, measure with CH1 at pin 6 or 2 and with CH2 at pin 3 the signals period and duty cycle (use reading at pin 3) at three different speeds – very low, medium, and full speed. Record your measurements

Low speed		Medium speed		High speed	
T	Duty	T	Duty	T	Duty

Measure across the motor simultaneously with the oscilloscope and the DMM (set the instrument in Vdc) at the same three speeds selected before

Low speed		Medium speed		High speed	
Duty	DMM	Duty	DMM	Duty	DMM

WEEK 15

Course Review

Notes

Notes

Notes

Notes

WEEK 16

~ FINAL ~

FINAL STUDY GUIDE

Appendixes

SIEMENS

Final Exam

Final Exam

The final exam is intended to be a learning tool. The book may be used during the exam. A tear-out answer sheet is provided. After completing the test, mail the answer sheet in for grading. A grade of 70% or better is passing. Upon successful completion of the test a certificate will be issued. Those receiving a score of less than 70% will be provided a second test.

Questions

1. A material that is a good insulator is

   a. copper
   b. aluminum
   c. silver
   d. rubber

2. A material with more protons than electrons has a

   a. negative charge
   b. positive charge
   c. neutral charge
   d. no charge

3. In a simple electric circuit with a 12 volt supply, and a 24 Ω resistor, current is

   a. 2 amps
   b. 5 amps
   c. .2 amps
   d. .5 amps

4. The total resistance in a series circuit containing 10 Ω, 10 Ω, and 10 Ω resistors is

   a. 10 Ω
   b. 30 Ω
   c. 3.33 Ω
   d. 100 Ω

5. In a 12 volt series circuit where $R_1 = 10\,\Omega$, $R_2 = 20\,\Omega$, and $R_3 = 10\,\Omega$, current flow through R_2 is

   a. .3 amps
   b. .5 amps
   c. .25 amps
   d. 3.33 amps

6. In a circuit containing three 30 Ω resistors in parallel, the total resistance is

   a. 30 Ω
   b. 90 Ω
   c. 10 Ω
   d. .1 Ω

7. The rate at which work is done is called

   a. energy
   b. power
   c. efficiency
   d. power factor

8. Power in a simple 12 volt, 4 amp series circuit is

   a. 3 amps
   b. 3 watts
   c. 48 amps
   d. 48 watts

9. The instantaneous voltage at 150 degrees of an AC sine wave whose peak voltage is 480 volts is

   a. 415.7 volts
   b. 480 volts
   c. 240 volts
   d. 0 volts

10. The effective voltage of an AC sine wave whose peak voltage is 480 volts is

    a. 415.7 volts
    b. 339.4 volts
    c. 480 volts
    d. 679 volts

11. The time constant of a series circuit with a 10 millihenry inductor, and a 5 Ω resistor is

    a. 2 milliseconds
    b. 2 seconds
    c. 2 microseconds
    d. .5 seconds

12. The total inductance of a series circuit containing a 10 mh, 20 mh, and 40 mh inductors is

    a. 5.7 pF
    b. 5.7 mh
    c. 70 Ω
    d. 70 mh

13. The time constant for a series circuit with a 20 Ω resistive and a 4 µF capacitor is

    a. 80 microseconds
    b. 80 milliseconds
    c. 5 microseconds
    d. 5 milliseconds

14. Total capacitance for a series circuit containing a 2 µF, 4 µF, and 8 µF capacitors is

a. 14 µF
b. .875 µF
c. 1.14 µF
d. 4 µF

15. Total opposition to current flow in an AC circuit that contains both reactance and resistance is called

a. resistance
b. reactance
c. impedance
d. capacitance

16. In a 60 hertz circuit containing 5 millihenrys of inductance, inductive reactance is

a. 1.884 Ω
b. 1884 Ω
c. .0005 Ω
d. .05 Ω

17. In a purely inductive circuit

a. current leads voltage by 90 degrees
b. current lags voltage by 90 degrees
c. current and voltage are in phase
d. current leads voltage by 30 degrees

18. In a series AC circuit with a 20 Ω resistor and a 10 Ω inductive reactance, impedance is

a. 30 Ω
b. 10 Ω
c. 14.1 Ω
d. 22.4 Ω

19. A series AC circuit containing more capacitive reactance than inductive reactance is

a. inductive
b. resistive
c. capacitive
d. in phase

20. An iron-core transformer with 120 volt, 10 amp primary, and 5 amp secondary is a

a. step down transformer with a 60 volt secondary
b. step up transformer with a 240 volt secondary
c. step up transformer with a 480 volt secondary
d. step down transformer with a 30 volt secondary

Siemens STEP 2000
Test Answer Form

❶ Select the STEP 2000 course you are testing.

- ❑ Basics of Electricity
- ❑ Basics of Electrical Products
- ❑ AC Motors
- ❑ Basics of AC Drives
- ❑ Basics of Control Components
- ❑ Basics of PLCs
- ❑ Basics of Sensors
- ❑ General Motion Control
- ❑ Motor Control Centers
- ❑ Busway
- ❑ Load Centers
- ❑ Molded Case Circuit Breakers
- ❑ Panelboards
- ❑ Power Monitoring and Management with ACCESS
- ❑ Safety Switches
- ❑ Switchboards

❷ Tell us about you.

First Name	Last Name	
Company Name		
Title		
Mailing Address		
City	ST	ZIP
Phone	ext	
Fax	email	

❸ Fill in your answers below.

	a	b	c	d		a	b	c	d
1.	❍	❍	❍	❍	11.	❍	❍	❍	❍
2.	❍	❍	❍	❍	12.	❍	❍	❍	❍
3.	❍	❍	❍	❍	13.	❍	❍	❍	❍
4.	❍	❍	❍	❍	14.	❍	❍	❍	❍
5.	❍	❍	❍	❍	15.	❍	❍	❍	❍
6.	❍	❍	❍	❍	16.	❍	❍	❍	❍
7.	❍	❍	❍	❍	17.	❍	❍	❍	❍
8.	❍	❍	❍	❍	18.	❍	❍	❍	❍
9.	❍	❍	❍	❍	19.	❍	❍	❍	❍
10.	❍	❍	❍	❍	20.	❍	❍	❍	❍

❹ Send this Test Answer Form to EandM for grading.

If you achieve a score of 70% or better and live in Northern California, we'll send you a certificate of completion! If you have any questions, contact EandM Training at 866.693.2636 or fax 707.473.3190 or training@eandm.com.

Attn: Step 2000 Training Department
EandM
55 Francisco Street Suite 330
San Francisco, CA 94133
707.473.3190 fax

Excerpts from "DOE Fundamentals – Mathematics – Manual FSC – 6910"

Scientists, engineers, operators, and technicians use scientific notation when working with very large and very small numbers. The speed of light is 29,900,000,000 centimeters per second; the mass of an electron is 0.000549 atomic mass units. It is easier to express these numbers in a shorter way called scientific notation, thus avoiding the writing of many zeros and transposition errors.

$$29{,}900{,}000{,}000 = 2.99 \times 10^{10}$$
$$0.000549 = 5.49 \times 10^{-4}$$

Writing Numbers in Scientific Notation

To transform numbers from decimal form to scientific notation, it must be remembered that the laws of exponents form the basis for calculations using powers.

The following whole numbers and decimals can be expressed as powers of 10:

$1 = 10^0$
$10 = 10^1$
$100 = 10^2$
$1000 = 10^3$
$10{,}000 = 10^4$

$0.1 = 1/10 = 10^{-1}$
$0.01 = 1/100 = 10^{-2}$
$0.001 = 1/1000 = 10^{-3}$

A number N is in scientific notation when it is expressed as the product of a decimal number between 1 and 10 and some integer power of 10.

$$N = a \times 10^n \quad \text{where } 1 \leq a < 10 \text{ and } n \text{ is an integer.}$$

The steps for converting to scientific notation are as follows:

Step 1: Place the decimal immediately to the right of the left-most non-zero number.
Step 2: Count the number of digits between the old and new decimal point.
Step 3: If the decimal is shifted to the left, the exponent is positive. If the decimal is shifted to the right, the exponent is negative.

Let us examine the logic of this. Consider as an example the number 3750. The number will not be changed if it is multiplied by 1000 and divided by 1000 (the net effect is to multiply it by one). Then,

$$\frac{3750}{1000} \times 1000 = 3.750 \times 1000 = 3.750 \times 10^3$$

There is a division by 10 for each space the decimal point is moved to the left, which is compensated for by multiplying by 10. Similarly, for a number such as .0037, we multiply the number by 10 for each space the decimal point is moved to the right. Thus, the number must be divided by 10 for each space.

$$.0037 = .0037 \times \frac{1}{10} \times \frac{1}{10} \times \frac{1}{10} = \frac{3.7}{10^3} = 3.7 \times 10^{-3}$$

Example 1:

Circulating water flows at 440,000 gallons per minute. Express this number in scientific notation.

Solution:

440,000 becomes 4.4 x 10^n

4 4 0 0 0 0.
5 4 3 2 1

n = +5 because the decimal is shifted five places to the left.

440,000 = 4.4 x 10^5

Example 2:

Express 0.0000247 in scientific notation.

Solution:

0. 0 0 0 0 2 4 7
1 2 3 4 5

n= -5 because the decimal is shifted five places to the right.

0.0000247 = 2.47 x 10^{-5}

Example 3:

Express 34.2 in scientific notation.

Solution:

3 4. 2
1

n= 1 because the decimal is shifted one place to the left.

34.2 = 3.42 x 10^1

Converting Scientific Notation to Integers

Often, numbers in scientific notation need to be put in integer form.

To convert scientific notation to integers:

Step 1: Write decimal number.

Step 2: Move the decimal the number of places specified by the power of ten: to the right if positive, to the left if negative. Add zeros if necessary.

Step 3: Rewrite the number in integer form.

Example:

Convert 4.4×10^3 to integer form.

Solution:

Step 1: 4.4

Step 2: $4.\underbrace{4}_{1}\underbrace{0}_{2}\underbrace{0}_{3}$

Step 3: $4.4 \times 10^3 = 4400$

ABCs of DMMs

Multimeter features and functions explained

Fluke Education Partnership Program

Application Note

Introduction

Multimeters. They've been described as the tape measure of the new millennium. But what exactly is a digital multimeter (DMM) and what can you do with it? How do you make measurements safely? What features do you need? What is the easiest way to get the most out of your meter? Which meter is best suited to the environment you're working in? These and other questions are answered in this application note.

Technology is rapidly changing our world. Electrical and electronic circuitry seems to permeate everything, and continues to get more complex and smaller in size. The communication industry booms with cell phones and pagers, and Internet connections have put more pressure on the electronics technician. Servicing, repairing, and installing this complex equipment requires diagnostic tools that provide accurate information.

Let's begin by explaining what a DMM is. A DMM is simply an electronic tape measure for making electrical measurements. It may have any number of special features, but mainly a DMM measures volts, ohms, and amperes.

Fluke DMMs are used for examples in this application note. Other DMMs may operate differently or offer different features from the ones shown. However, this application note explains common uses and tips for using most DMMs. In the next few pages, we will discuss how to use a DMM to make measurements, and how DMMs differ from one another.

Choosing your DMM

Choosing a DMM for the job requires not only looking at basic specifications, but also looking at features, functions, and the overall value represented by a meter's design and the care taken in its production.

Reliability, especially under tough conditions, is more important than ever today. Another important factor is safety. Providing adequate component spacing, double insulation, and input protection helps prevent injury and meter damage when they are used improperly. Choose a DMM designed to the latest, most demanding safety standards.

Fluke offers many DMMs with different combinations of features like Touch Hold®, analog bar graphs, and enhanced resolution. Accessories for high current and temperature measurements are available to extend the capabilities of DMMs.

Some basics

Resolution, digits and counts

Resolution refers to how fine a measurement a meter can make. By knowing the resolution of a meter, you can determine if it is possible to see a small change in the measured signal. For example, if the DMM has a resolution of 1 mV on the 4 V range, it is possible to see a change of 1 mV (1/1000 of a volt) while reading 1 V.

You wouldn't buy a ruler marked in one-inch (or one-centimeter) segments if you had to measure down to a quarter inch (or one millimeter). A thermometer that measures only in whole degrees isn't much use when your normal temperature is 98.6 degrees Fahrenheit. You need a thermometer with one-tenth degree *resolution*.

The terms *digits* and *counts* are used to describe a meter's resolution. DMMs are grouped by the number of counts or digits they display.

Digital multimeters offer a wide selection of features. Choosing the right meter for the job can be challenging unless you know what the features do. This application note explains some of the most common features and how they can be used in actual applications.

A 3½-digit meter can display three full digits ranging from 0 to 9, and one "half" digit which displays only a 1 or is left blank. A 3½-digit meter will display up to 1,999 counts of resolution. A 4½-digit meter can display up to 19,999 counts of resolution.

It is more precise to describe a meter by counts of resolution than by digits. Today's 3½-digit meters may have enhanced resolution of up to 3,200, 4,000, or 6,000 counts.

For certain measurements, 3,200-count meters offer better resolution. For example, a 1,999-count meter won't be able to measure down to a tenth of a volt if you are measuring 200 volts or more. However, a 3,200-count meter will display a tenth of a volt up to 320 volts. This is the same resolution as a more expensive 20,000-count meter until you exceed 320 volts.

Accuracy

Accuracy is the largest allowable error that will occur under specific operating conditions. In other words, it is an indication of how close the DMM's displayed measurement is to the actual value of the signal being measured.

Accuracy for a DMM is usually expressed as a *percent of reading*. An accuracy of one percent of reading means that for a displayed reading of 100 volts, the actual value of the voltage could be anywhere between 99 volts and 101 volts.

Specifications may also include a range of digits added to the basic accuracy specification. This indicates how many counts the digit to the extreme right of the display may vary. So the preceding accuracy example might be stated as ± (1 % + 2). Therefore, for a display reading of 100 volts, the actual voltage would be between 98.8 volts and 101.2 volts.

Analog meter specifications are determined by the error *at full scale*, not at the displayed reading. Typical accuracy for an analog meter is ± 2 % or ± 3 % of full scale. At one-tenth of full scale, these become 20 percent or 30 percent *of reading*. Typical basic accuracy for a DMM is between ± (0.7 % + 1) and ± (0.1 % + 1) *of reading*, or better.

Ohm's law

Voltage, current, and resistance in any electrical circuit can be calculated by using Ohm's Law, which states that voltage equals current times resistance (see Figure 1). Thus, if any two values in the formula are known, the third can be determined.

A DMM makes use of Ohm's Law to directly measure and display either ohms, amps, or volts. On the following pages, you will see just how easy it is to use a DMM to find the answers you need.

Digital and analog displays

For high accuracy and resolution, the digital display excels, displaying three or more digits for each measurement.

The analog needle display is less accurate and has lower effective resolution because you have to estimate values between the lines.

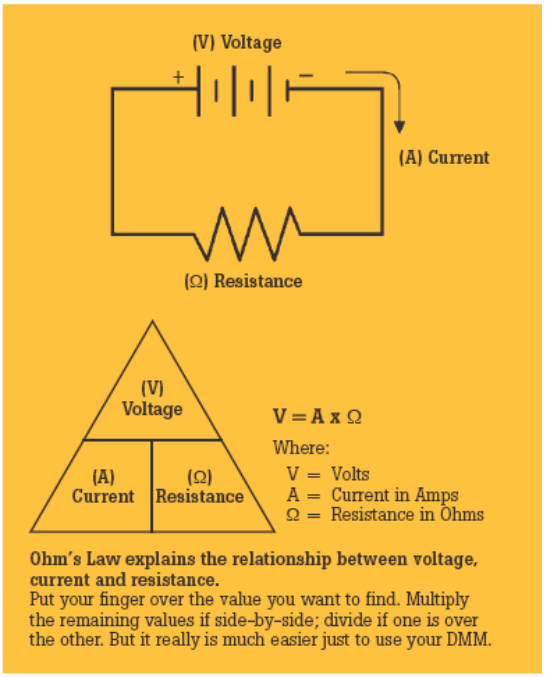
A bar graph shows changes and trends in a signal just like an analog needle, but is more durable and less prone to damage.

DC and AC voltage

Measuring voltage

One of the most basic tasks of a DMM is measuring voltage. A typical dc voltage source is a battery, like the one used in your car. AC voltage is usually created by a generator. The wall outlets in your home are common sources of ac voltage. Some devices convert ac to dc. For example, electronic equipment such as TVs, stereos, VCRs, and computers that you plug into an ac wall outlet use devices called rectifiers to convert the ac voltage to a dc voltage. This dc voltage is what powers the electronic circuits in these devices.

Testing for proper supply voltage is usually the first step when troubleshooting a circuit. If there is no voltage present, or if it is too high or too low, the voltage problem should be corrected before investigating further.



Ohm's Law explains the relationship between voltage, current and resistance.
Put your finger over the value you want to find. Multiply the remaining values if side-by-side; divide if one is over the other. But it really is much easier just to use your DMM.

Figure 1.

The waveforms associated with ac voltages are either sinusoidal (sine waves), or non-sinusoidal (sawtooth, square, ripple, etc.). True-rms DMMs display the "rms" (root mean square) value of these voltage waveforms. The rms value is the effective or equivalent dc value of the ac voltage.

Many DMMs are "average responding," giving accurate rms readings if the ac voltage signal is a pure sine wave. Average responding meters are not capable of measuring non-sinusoidal signals accurately. Non-sinusoidal signals are accurately measured using DMMs designated "true-rms" up to the DMM's specified crest factor. Crest factor is the ratio of a signal's peak-to-rms value. It's 1.414 for a pure sine wave, but is often much higher for a rectifier current pulse, for example. As a result, an average responding meter will often read much lower than the actual rms value.

A DMM's ability to measure ac voltage can be limited by the frequency of the signal. Most DMMs can accurately measure ac voltages with frequencies from 50 Hz to 500 Hz, but a DMM's ac measurement bandwidth may be hundreds of kilohertz wide. Such a meter may read a higher value because it is "seeing" more of a complex ac signal. DMM accuracy specifications for ac voltage and ac current should state the frequency range along with the range's accuracy.

How to make voltage measurements

1. Select V~ (ac) or V⎓ (dc), as desired.
2. Plug the black test probe into the COM input jack. Plug the red test probe into the V input jack.
3. If the DMM has manual ranging only, select the highest range so as not to overload the input.
4. Touch the probe tips to the circuit across a load or power source (in parallel to the circuit). ⚠
5. View the reading, being sure to note the unit of measurement.

Note: For dc readings of the correct polarity (±), touch the red test probe to the positive side of the circuit, and the black probe to the negative side or circuit ground. If you reverse the connections, a DMM with autopolarity will merely display a minus sign indicating negative polarity. With an analog meter, you risk damaging the meter.

Note: 1/1000 V = 1 mV
1000 V = 1 kV

⚠ High-voltage probes are available for TV and CRT repair, where voltages can reach 40 kV (see Figure 3).

Caution: These probes are not intended for electrical utility applications in which high voltage is also accompanied by high energy. Rather, they are intended for use in low-energy applications.

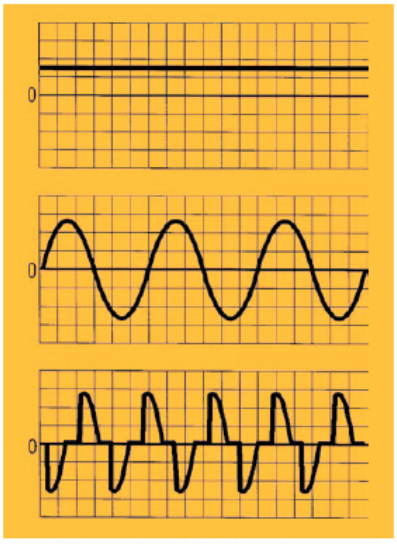


Figure 2. Three voltage signals: dc, ac sine wave, and non-sinusoidal ac signal.

Figure 3. Accessories, such as high-voltage probes, extend the voltage measurement range of a DMM.

Resistance, continuity and diodes

Resistance

Resistance is measured in ohms (Ω). Resistance values can vary greatly, from a few milliohms (mΩ) for contact resistance to billions of ohms for insulators. Most DMMs measure down to 0.1 Ω, and some measure as high as 300 MΩ (300,000,000 ohms). Infinite resistance (open circuit) is read as "OL" on the Fluke meter display, and means the resistance is greater than the meter can measure.

Resistance measurements must be made with the circuit power off – otherwise, the meter or circuit could be damaged. Some DMMs provide protection in the ohms mode in case of accidental contact with voltages. The level of protection may vary greatly among different DMM models.

For accurate, low-resistance measurements, resistance in the test leads must be subtracted from the total resistance measured. Typical test lead resistance is between 0.2 Ω and 0.5 Ω. If the resistance in the test leads is greater than 1 Ω, the test leads should be replaced.

If the DMM supplies less than 0.6 V dc test voltage for measuring resistance, it will be able to measure the values of resistors that are isolated in a circuit by diodes or semiconductor junctions. This often allows you to test resistors on a circuit board without unsoldering them (see Figure 4).

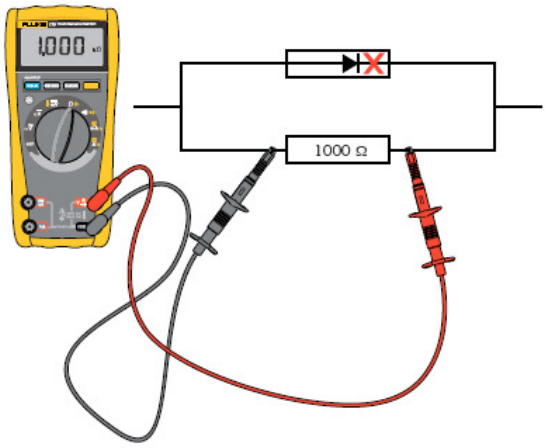


Figure 4. For measuring resistance in the presence of diodes, DMM test voltages are kept below 0.6 V so the semiconductor junctions do not conduct current.

How to make resistance measurements:

1. ⚠ Turn off power to the circuit.
2. Select resistance (Ω).
3. Plug the black test probe into the COM input jack. Plug the red test probe into the Ω input jack.
4. Connect the probe tips across the component or portion of the circuit for which you want to determine resistance.
5. View the reading, being sure to note the unit of measurement – ohms (Ω), kilohms (kΩ), or megohms (MΩ).

Note: 1,000 Ω = 1 kΩ
1,000,000 Ω = 1 MΩ

⚠ Make sure the power is off before making resistance measurements.

Continuity

Continuity is a quick go/no-go resistance test that distinguishes between an open and a closed circuit.

A DMM with a continuity beeper allows you to complete many continuity tests easily and quickly. The meter beeps when it detects a closed circuit, so you don't have to look at the meter as you test. The level of resistance required to trigger the beeper varies from model to model of DMM.

Diode test

A diode is like an electronic switch. It can be turned on if the voltage is over a certain level, generally about 0.6 V for a silicon diode, and it allows current to flow in one direction.

When checking the condition of a diode or transistor junction, an analog VOM not only gives widely varying readings but can drive currents up to 50 mA through the junction. (See Table 1).

Some DMMs have a diode test mode. This mode measures and displays the actual voltage drop across a junction. A silicon junction should have a voltage drop less than 0.7 V when applied in the forward direction and an open circuit when applied in the reverse direction.

DC and AC current

Measuring current

Current measurements are different from other DMM measurements. Current measurements taken with the DMM alone require placing the meter in series with the circuit being measured. This means opening the circuit and using the DMM test leads to complete the circuit. This way all the circuit current flows through the DMM's circuitry. An indirect method of measuring current on a DMM can be performed using a current probe. The probe clamps around the outside of the conductor, thus avoiding opening the circuit and connecting the DMM in series.

How to make current measurements

1. Turn off power to the circuit.
2. Cut or unsolder the circuit, creating a place where the meter probes can be inserted.
3. Select A~ (ac) or A⎓ (dc) as desired.
4. Plug the black test probe into the COM input jack. Plug the red test probe into the amp or milliamp input jack, depending on the expected value of the reading.
5. Connect the probe tips to the circuit across the break so that all current will flow through the DMM (a series connection).
6. Turn the circuit power back on.
7. View the reading, being sure to note the unit of measurement.

Note: If the test leads are reversed for a dc measurement, a "–" will show in the display.

Input protection

A common mistake is to leave the test leads plugged into the current input jacks and then attempt a voltage measurement. This causes a direct short across the source voltage through a low-value resistor inside the DMM, called a current shunt. A high current flows through the DMM and if it is not adequately protected, can cause extreme damage to both the DMM and the circuit, and possible injury to the operator. Extremely high fault currents can occur if industrial high-voltage circuits are involved (240 V or higher).

A DMM should therefore have current input fuse protection of high enough capacity for the circuit being measured. Meters without fuse protection in the current inputs should not be used on high-energy electrical circuits (> 240 V ac). Those DMMs that do use fuses should have a fuse with sufficient capacity to clear a high-energy fault. The voltage rating of the meter's fuses should be greater than the maximum voltage you expect to measure. For example, a 20 A, 250 V fuse may not be able to clear a fault inside the meter when the meter is across a 480 V circuit. A 20 A, 600 V fuse would be needed to clear the fault on a 480 V circuit.

Current probe accessories

Sometimes you may have to make a current measurement that exceeds the rating of your DMM or the situation does not allow you to open the circuit to measure the current. In these higher current applications (typically over 2 A), where high accuracy is not needed, a current probe is very useful. A current probe clamps around the conductor carrying the current, and it converts the measured value to a level the meter can handle.

	VOM	VOM	DMM
Range	Rx1	Rx100	Diode Test
Junction Current	35 mA - 50 mA	0.5 mA - 1.5 mA	0.5 mA - 1 mA
Germanium	8 Ω - 19 Ω	200 Ω - 300 Ω	0.225 V - 0.225 V
Silicon	8 Ω - 16 Ω	450 Ω - 800 Ω	0.4 V - 0.6 V

Table 1.

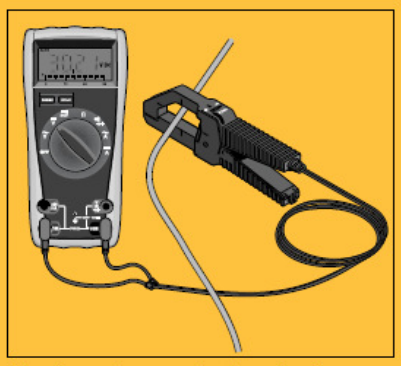
There are two basic types of current probes: current transformers, which are used to measure ac current only, and Hall-Effect probes, which are used to measure ac or dc current.

The output of a current transformer is typically *1 milliamp per amp*. A 100 amp value is reduced to 100 milliamps, which can be safely measured by most DMMs. The probe leads are connected to the "mA" and "COM" input jacks, and the meter function switch is set to mA ac.

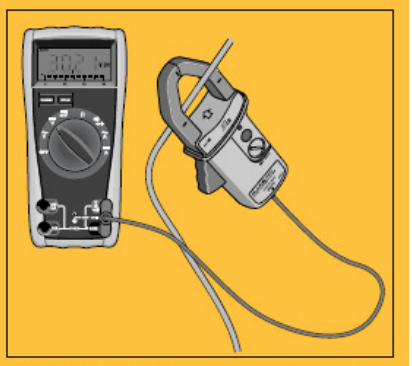
The output of a Hall-Effect probe is *1 millivolt per amp, ac or dc*. For example, 100 A ac is converted to 100 mV ac. The probe leads are connected to the "V" and "COM" jacks. Set the meter function switch to the "V" or "mV" scale, selecting V~ for ac current or V⎓ for dc current measurements. The meter displays 1 millivolt for every amp measured.

⚠ Always make sure the power if off before cutting or unsoldering the circuit and inserting the DMM for current measurements. Even small amounts of current can be dangerous.

⚠ Never attempt a voltage measurement with the test probes in the current jack. Meter damage or personal injury may result.



A transformer-type current probe, such as the one depicted above, scales down the current being measured. The DMM displays 1 mA for every amp being measured.



A Hall-Effect probe safely measures high-current ac or dc values by scaling down the current being measured and converting this reduced current to a voltage. The DMM displays 1 mV for every amp.

Figure 5.

Safety

Multimeter safety

Making measurements safely starts with choosing the proper meter for the application as well as the environment in which the meter will be used. Once the proper meter has been chosen, you should use it by following good measurement procedures. Carefully read the instrument user manual before use, paying particular attention to the **WARNING** and **CAUTION** sections.

The International Electrotechnical Commission (IEC) established safety standards for working on electrical systems. Make sure you are using a meter that meets the IEC category and voltage rating approved for the environment where the measurement is to be made. For instance, if a voltage measurement needs to be made in an electrical panel with 480 V, then a meter rated Category III 600 V or 1000 V should be used. This means the input circuitry of the meter has been designed to withstand voltage transients commonly found in this environment without harming the user. Choosing a meter with this rating which also has a UL, CSA, VDE or TÜV certification means the meter not only has been designed to IEC standards, but has been independently tested and meets those standards. (See Independent Testing sidebar on Page 6)

Common situations that lead to DMM failure:

1. Contact with ac power source while test leads are plugged into current jacks
2. Contact with ac power source while in resistance mode
3. Exposure to high voltage transients
4. Exceeding maximum input limitations (voltage and current)

Types of DMM protection circuits:

1. **Protection with automatic recovery.** Some meters have circuitry that detects an overload condition and protects the meter until the condition no longer exists. After the overload is removed, the DMM automatically returns to normal operation. Usually used to protect the ohms function from voltage overloads.
2. **Protection without automatic recovery.** Some meters will detect an overload condition and protect the meter, but will not recover until the operator performs an operation on the meter, such as replacing a fuse.

Look for these safety features in a DMM:

1. Fused current inputs
2. Use of high-energy fuses (600 V or more)
3. High-voltage protection in resistance mode (500 V or more)
4. Protection against voltage transients (6 kV or more)
5. Safety-designed test leads with finger guards and shrouded terminals
6. Independent safety organization approval/listing (e.g., UL or CSA)

Safety checklist

- ✓ Use a meter that meets accepted safety standards for the environment in which it will be used.
- ✓ Use a meter with fused current inputs and be sure to check the fuses before making current measurements.
- ✓ Inspect test leads for physical damage before making a measurement.
- ✓ Use the meter to check continuity of the test leads.
- ✓ Use only test leads that have shrouded connectors and finger guards.
- ✓ Use only meters with recessed input jacks.
- ✓ Select the proper function and range for your measurement.
- ✓ Be certain the meter is in good operating condition.
- ✓ Follow all equipment safety procedures.
- ✓ Always disconnect the "hot" (red) test lead first.
- ✓ Don't work alone.
- ✓ Use a meter that has overload protection on the ohms function.
- ✓ When measuring current without a current clamp, turn the power off before connecting into the circuit.
- ✓ Be aware of high-current and high-voltage situations and use the appropriate equipment, such as high-voltage probes and high-current clamps.

Accessories and glossary

DMM accessories

One very important requirement of a DMM is that it can be used with a wide variety of accessories. Many accessories are available that can increase your DMM's measurement range and usefulness, while making your measurement tasks easier.

High-voltage probes and current probes scale down high voltages and currents to a level the DMM can safely measure. Temperature probes convert your DMM into a handy digital thermometer. RF probes can be used to measure voltages at high frequencies.

Furthermore, a selection of test leads, test probes, and test clips can help you easily connect your DMM to the circuit. Soft and hard carrying cases protect your DMM and conveniently store your accessories with your DMM.

Glossary

Accuracy. How close the DMM's displayed measurement is to the actual value of the signal being measured. Expressed as a percentage of reading or as a percentage of full scale.

Analog meter. An instrument that uses a needle movement to display the value of a measured signal. The user judges the reading based on the position of the needle on a scale.

Annunciator. A symbol that identifies a selected range or function.

Average responding DMM. A DMM that accurately measures sinusoidal waveforms, while measuring non-sinusoidal waveforms with less accuracy.

Count. A number used to specify a DMM's resolution.

Current-shunt. A low-value resistor in a DMM for measuring current. The DMM measures the voltage drop across the current shunt and, using Ohm's Law, calculates the value of the current.

DMM, digital multimeter. An instrument that uses a digital display to show the value of a measured signal. DMMs feature greater durability, resolution, and far more accuracy than analog meters.

Non-sinusoidal waveform. A distorted waveform such as a pulse train, square waves, triangular waves, sawtooth waves and spikes.

Resolution. The degree to which small changes in a measurement can be displayed.

rms. The equivalent dc value of an ac waveform.

Sinusoidal waveform. A pure sine wave without distortion.

True-rms DMM. A DMM that can accurately measure both sinusoidal and non-sinusoidal waveforms.

Meter ratings and capabilities vary by manufacturer. Before working with a new meter, be sure to familiarize yourself with all operating and safety procedures for that meter contained in the users manual.

Independent testing is the key to safety compliance

How can you tell if you're getting a genuine CAT III or CAT II meter? It's not always easy. It is possible for a manufacturer to self-certify its meters as CAT II or CAT III *without any independent verification*. Beware of wording such as "Designed to meet specifications..." Designer's plans are never a substitute for an actual independent test. The IEC (International Electrotechnical Commission) develops and proposes standards, but it is not responsible for *enforcing* the standards.

Look for the symbol and listing number of an independent testing lab such as UL, CSA, TÜV or other recognized approval agency. That symbol can only be used if the product successfully completed testing to the agency's standard, which is based on national/ international standards. UL 3111, for example, is based on IEC 1010. In an imperfect world, that is the closest you can come to ensuring that the multimeter you choose was actually *tested* for safety.

Special features

The following special features and functions may make it easier to use your DMM.

- Annunciators show at a glance what is being measured (volts, ohms, etc.).
- Touch Hold® freezes the display on stable readings so you can use both hands to take a measurement and view results later.
- One-switch operation makes it easy to select measurement functions.
- Overload protection prevents damage to both the meter and the circuit, while protecting the user.
- Special high-energy fuses provide extra protection for user and meter during current measurements and overloads.
- Autoranging automatically selects proper measurement range. Manual ranging lets you lock into a specific range for repetitive measurements.
- Autopolarity indicates negative readings with a minus sign, so even if you connect the test leads in reverse you won't damage the meter.
- Low battery indicator.

Fluke Corporation
PO Box 9090, Everett, WA USA 98206
©2003 Fluke Corporation. All rights reserved.
Printed in U.S.A. 6/2003 2100079 A-ENG-N Rev A

Web access: http://www.fluke.com

10 dumb things smart people do when testing electricity

Fluke Education Partnership Program

Application Note

Anyone who makes their living by working with electricity quickly develops a healthy respect for anything with even a remote chance of being "live." Yet the pressures of the getting a job done on time or getting a mission-critical piece of equipment back on line can result in carelessness and uncharacteristic mistakes by even the most seasoned electrician. The list below was developed as a quick reminder of what *not* to do when taking electrical measurements.

1. **Replace the original fuse with a cheaper one.** If your digital multimeter (DMM) meets today's safety standards, that fuse is a special safety sand fuse designed to pop before an overload hits your hand. When you change your DMM fuse, be sure to replace it with an authorized fuse.
2. **Use a bit of wire or metal to get around the fuse all together.** That may seem like a quick fix if you're caught without an extra fuse, but that fuse could be all that ends up between you and a spike headed your way.
3. **Use the wrong test tool for the job.** It's important to match your DMM to the work ahead. Make sure your test tool holds the correct CAT rating for each job you do, even if it means switching DMMs throughout the day.
4. **Grab the cheapest DMM on the rack.** You can upgrade later, right? Maybe not, if you end up a victim of a safety accident because that cheap test tool didn't actually contain the safety features it advertised. Look for independent laboratory testing.
5. **Leave your safety glasses in your shirt pocket.** Take them out. Put them on. It's important. Ditto insulated gloves and flame-resistant clothing.
6. **Work on a live circuit.** De-energize the circuit whenever possible. If the situation requires you to work on a live circuit, use properly insulated tools, wear safety glasses or a face shield and insulated gloves, remove watches or other jewelry, stand on an insulated mat and wear flame-resistant clothing, not regular work clothes.
7. **Fail to use proper lock-out/tag-out procedures.**
8. **Keep both hands on the test.** Don't! When working with live circuits, remember the old electrician's trick. Keep one hand in your pocket. That lessens the chance of a closed circuit across your chest and through your heart. Hang or rest the meter if possible. Try to avoid holding it with your hands to minimize personal exposure to the effects of transients. For hazardous measurement applications additional measures for reducing the risk of hazard and arc flash should be considered. These include the use of protective equipment including gloves, clothing, and eyewear as prescribed by NFPA 70 E and NEC (National Electrical Code) Article 110.16 for flash protection plus consideration for additional local government and country requirements.
9. **Neglect your leads.** Test leads are an important component of DMM safety. Make sure your leads match the CAT level of your job as well. Look for test leads with double insulation, shrouded input connectors, finger guards and a non-slip surface.

10. **Hang onto your old test tool forever.** Today's test tools contain safety features unheard of even a few years ago, features that are worth the cost of an equipment upgrade and a lot less expensive than an emergency room visit.

Overvoltage category	In brief	Examples
CAT IV	Three-phase at utility connection, any outdoor conductors	• Refers to the "origin of installation"; i.e., where low-voltage connection is made to utility power. • Electricity meters, primary overcurrent protection equipment. • Outside and service entrance, service drop from pole to building, run between meter and panel. • Overhead line to detached building, underground line to well pump.
CAT III	Three-phase distribution, including single-phase commercial lighting	• Equipment in fixed installations, such as switchgear and polyphase motors. • Bus and feeder in industrial plants. • Feeders and short branch circuits, distribution panel devices. • Lighting systems in larger buildings. • Appliance outlets with short connections to service entrance.

CAT II	Single-phase receptacle connected loads	• Appliance, portable tools, and other household and similar loads.
		• Outlet and long branch circuits.
		  • Outlets at more than 10 meters (30 feet) from CAT III source.
		  • Outlets at more that 20 meters (60 feet) from CAT IV source.

CAT I	Electronic	• Protected electronic equipment. • Equipment connected to (source) circuits in which measures are taken to limit transient overvoltages to an appropriately low level. • Any high-voltage, low-energy source derived from a high-winding resistance transformer, such as the high-voltage section of a copier.

Overvoltage installation categories. IEC 61010 applies to *low-voltage* (< 1000 V) test equipment.

- ✯ KNOWLEDGE
- ✯ CRAFTMANSHIP
- ✯ TENACITY
- ✯ INTEGRITY